REPORT 4

SWEEP

SOIL AND WATER
ENVIRONMENTAL
ENHANCEMENT PROGRAM

PAMPA

PROGRAMME D'AMELIORATION
DU MILIEU PEDOLOGIQUE
ET AQUATIQUE

Canada

Ontario

SWEEP

is a $30 million federal-provincial agreement, announced May 8, 1986, designed to improve soil and water quality in southwestern Ontario over the next five years.

PURPOSES

There are two interrelated purposes to the program; first, to reduce phosphorus loadings in the Lake Erie basin from cropland run-off; and second, to improve the productivity of southwestern Ontario agriculture by reducing or arresting soil erosion that contributes to water pollution.

BACKGROUND

The Canada-U.S. Great Lakes Water Quality Agreement called for phosphorus reductions in the Lake Erie basin of 2000 tonnes per year. SWEEP is part of the Canadian agreement, calling for reductions of 300 tonnes per year — 200 from croplands and 100 from industrial and municipal sources.

PAMPA

est une entente fédérale-provinciale de 30 millions de dollars, annoncée le 8 mai 1986, et destinée à améliorer la qualité du sol et de l'eau dans le Sud-ouest de l'Ontario.

SES BUTS

Les deux buts de PAMPA sont: en premier lieu de réduire de 200 tonnes par an d'ici 1990 le déversement dans le lac Erie de phosphore provenant des terres agricoles, et de maintenir ou d'accroître la productivité agricole du Sud-ouest de l'Ontario, en réduisant ou en empêchant l'érosion et la dégradation du sol.

SES GRANDES LIGNES

L'entente entre le Canada et les États-Unis sur la qualité de l'eau des Grands Lacs prévoyait de réduire de 2 000 tonnes par an la pollution due au phosphore dans le bassin du lac Erie. PAMPA fait partie de cette entente qui réduira cette pollution de 300 tonnes par an — 200 tonnes provenant des terres agricoles et 100 tonnes provenant de sources industrielles et municipales.

100-05199/

TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

ASSESSMENT OF SOIL COMPACTION AND STRUCTURAL DEGRADATION IN THE LOWLAND CLAY SOILS

FINAL REPORT

MAY, 1988

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EXECUTIVE SUMMARY

Highlights of the major subject areas on subsoil compaction and structural degradation covered by this study in five counties in Southwestern Ontario are included in this summary. Recommendations and conclusions are based on results of field investigations, farmer interviews, laboratory analysis and review of scientific literature dealing with the problem of subsoil compaction on agricultural lands.

The Problem

This study focuses on the soil layer below the plow layer (i.e. about 15 to 30 cm below ground surface). Soil compaction may include one or more of these conditions: degraded soil structure; reduced size, abundance and continuity of vertical cracks and pores; smearing; increased soil bulk density; layering; and, altered rooting pattern and depth. These conditions tend to reduce the soils' ability to produce abundant crops due to deterioration of root zone quality. Soil permeability is also reduced and this results in increased runoff and erosion.

The main goal of this study was to determine the magnitude and extent of subsoil compaction and to evaluate its agricultural and environmental impacts.

Agro-environmental Setting

Southwestern Ontario is intensively farmed: the main crops grown being corn, cereals, beans (soy and white), hay and fresh vegetables.

Soils studied include predominantly clays, clay loams, silty clay loams, and silty clays on level to very gently undulating topography. Parent materials are either till, lacustrine deposits or lacustrine veneers over till. Soil drainage commonly ranges from imperfectly to poorly drained and many sites examined are tile drained.

To manage these fine textured, level soils for some of the crops grown, especially corn, many farmers try to get on their fields as early as possible in spring. The combination of tillage under fairly wet conditions using large, powerful and heavy tractors can contribute to soil compaction. Alternative cropping practices many be better for the soil but they may be

less profitable, at least in the short term. Research has demonstrated that compaction does not occur when soils are worked under proper moisture conditions.

Measurements of Compaction

Several methods are used to measure soil compaction and five of the more popular ways were used in this study: visual observations of a combination of factors; bulk density determinations, hand and cone penetrometer measurements and detailed descriptions of soil peds and pores (tubular and planar).

Statistical Analysis

The degree of compaction was assessed using various statistical procedures to establish relationships among measured and observed soil properties. A visual compaction rating proved to be a good measurement, although it is subjective. Resultant ratings into slight, moderate and severe compaction categories using this approach gave essentially the same results as using a combination of all measurement techniques.

A point transect method was used to locate study sites throughout the area in an attempt to obtain unbiased estimates on the extent of compaction.

Soil compaction measurements were statistically compared to various agronomic management practices to identify significant linkages. Items examined included different measurements of soil compaction, tractor size, crops, rotations, tillage practices, fertilization methods, weed control practices, harvesting, number of passes, and others.

Results

Soil compaction is a serious problem in Southwestern Ontario. Statistical analysis indicates that about 50 to 70 percent of the clay to clay loam soils in the Counties of Middlesex, Lambton, Essex, Kent and Elgin are affected. Of this total, about 25 percent are severely compacted and 75 percent are moderately affected. Impacts of compaction are estimated to be the following:

	Moderately Compacted	Severely Compacted
Crop Yield Reduction	12%	25%
Increased Soil Erosion	17%	39%
Increased Phosphorus Loadings to Great Lakes (kg/yr)	33,000	39,400

In terms of dollars, decreased yields represent by far the greatest shortfall on returns. Increased soil erosion is very important in that it is a hidden cost to the farmers and contributes sediments and nutrients to streams. However, from the farmers' viewpoint these costs are minor compared to yield losses. The phosphorus loadings to the Great Lakes attributable to compaction are in the order of 10 to 15 percent of the total phosphorus loadings from agricultural lands. It is noteworthy that soil husbandry practices undertaken to minimize or ameliorate the compaction problem to increase yields will simultaneously reduce the harmful environmental impacts.

Important factors considered to be contributing to compaction include:

Factor	
-Size of tractor	Increasing compaction related to bigger tractors
-Number of passes	More passes, especially when soils are wet
-Crops grown	Forages < small grains < row crops < silage corn and tomatoes

Natural amelioration of subsoil compaction through freeze-thaw and wetting-drying cycles is a slow process and is not practical in an agricultural time frame. Subsoiling using heavy duty chisel plows and subsoilers may be helpful but results to date are mixed. Further work is needed to determine the most effective methods of mechanically ameliorating compaction.

Management practices that farmers can implement to minimize or prevent compaction include:

-reduce vehicle weights below critical limits (dependent on soil conditions and tires)
-avoid traffic on wet or very moist fields
-limit the number of passes and control traffic

-utilize cropping systems which facilitate the above
-reduce tire pressures, unknown how beneficial duals are with respect to subsoil compaction
-using practices which maintain soil flora and fauna

Recommendations

Several questions arise from this study that should be answered in order to help farmers deal with the compaction problems. These include:

-refinement of visual methods for quickly assessing seriousness of compaction and compaction hazard considering soil characteristics and moisture conditions.

-better understanding of the role of rotations vs. monoculture, including crop yield and compaction relationships.

-research into the use of different tires (radials, duals, floatation tires, loading vs. slippage)

-development and application of computer models to make better estimates of the effects of compaction on erosion and phosphorus removal

-development of an integrated, holistic model for soil compaction which would allow a farmer to chose the best combination of cropping practices, machinery and tires for his soil conditions and farming operation.

1.0 INTRODUCTION

Can-Ag Enterprises was contracted by Supply and Services Canada on behalf of Agriculture Canada to conduct this evaluation of subsoil compaction under the Technology Evaluation and Development (TED) sub-program of the Soil and Water Environmental Enhancement Program (SWEEP).

Potential impacts of soil compaction on agricultural lands are all ultimately related to the soil's ability to produce abundant crops. The harmful effects of soil compaction which lead to reduced productivity include:

- degradation of soil tilth creating soil clods which require additional tillage operations and increased energy requirements,
- increased resistance for emerging seedlings,
- increased resistance to root penetration and reduction in effective rooting depth,
- reduced infiltration and subsurface permeabiltiy rates which can increase erosion by increasing runoff,and
- reduced pore size and continuity which retards water movement and the exchange of oxygen and carbon dioxide between the atmosphere and the root zone.

The first two effects relate primarily to topsoil compaction; remaining effects influence both topsoils and subsoils.

Crop productivity is adversely affected by compaction in one or more of the following ways:

- poor emergence results in reduced crop stands,
- crops may be subjected to increased moisture stress,
- nutrient uptake may be restricted,
- root zone aeration may be limited,
- there is evidence of harmful effects of residual chemicals, and
- restricted drainage may delay planting thereby limiting the choice of crops.

Soil compaction is measured in several ways, the main ones being bulk density determinations, soil strength measurements, porosity measurements, descriptions of visible soil features, and observations of crop growth.

The degree of compaction in soils is affected by soil texture,

organic matter content, moisture level, and structure. External factors causing compaction, such as farm machinery, are: pressures from tires on the land surface, pressures from tillage equipment in the process of cultivation, shearing and soil deformation under pressure.

1.1 OBJECTIVES

The objectives of the study were:

1. To determine the magnitude and extent of soil compaction and structural degradation on the flat, clay soils of Southwestern Ontario.
2. To assess the relative impact of soil compaction and structural degradation on phosphorus delivery and crop yield.
3. To evaluate the utility of existing knowledge of soil structure and subsoil compaction predictive models in assessing the nature and extent of the problem.
4. To evaluate prospective ameliorative techniques.
5. To recommend potential avenues for further research.

The study was initiated in November 1987 and involved three major types of data collection: field investigations of soils supported by laboratory analysis, farmer interviews, and a review of the literature. This report describes the methods used in collecting and statistically analyzing the data, presents the results and makes comparisons to findings reported in the literature, summarizes the study findings and gives recommendations for further work to help clarify data gaps and to help minimize compaction problems. A series of appendices provide abbreviations and definitions of classes used, summaries of data collected, and selected statistical analyses.

2.0 METHODS

2.1 FIELD INVESTIGATIONS

Initially, regional and county soils maps covering Southwestern Ontario were examined, areas of clay to clay loam soils were delineated and candidate study sites were selected. Considering soil distribution and the scope of the project, it was decided to limit the study area to five counties: Elgin, Essex, Kent, Lambton and Middlesex. In an attempt to obtain representative, unbiased results the field investigations were planned to proceed in two stages: Level 1- inspections and interviews with farmers at points along transects using procedures adapted from Wang (1982) to determine the percentage of sites with compaction and then extrapolate to estimate areas affects; and Level II - detailed examinations of soils and interviews with farmers at sites scattered throughout the study area to obtain more detailed information on clay to clay loam soils and on management practices that may not have been covered in the transects. Once fieldwork began procedures had to be changed slightly due to difficulty in quickly finding farmers at home. Further details on these activities are given below.

2.1.1 Level 1 - Inspections

In order to assess the areal extent and degree of compaction problems on clay soils in Southwestern Ontario a point transect method was utilized. One transect representing a cross section of clay soils, as mapped by previous county soil surveys, was selected for each of five counties: Middlesex, Lambton, Kent, Essex and Elgin. Along each transect five farms/sites at roughly equal spacings were chosen for examination. As close as possible to each of these sites a farmer (landowner) was contacted to obtain permission to conduct field investigations on his land and to complete a questionnaire regarding cropping history, management practices, yields, machinery used, etc. (sample questionnaire in Appendix). Then an examination of soils within two fields and a control (fencerow) was made.

The field examination consisted of first probing several sites

in a field with a shovel and quickly assessing the general condition of the plow layer and layer below plow depth. A site representative of the field was selected at which a soil pit was dug and a detailed soil morphological description made. The sites were always located at least 50 m from the field edge to avoid headland traffic zones.

The "simple system" for soil macrostructure described by McKeague et al. (1986) was also utilized in order to focus on void characteristics relevent to compaction and water flow. According to McKeague, "an ideal system for describing soil macrostructure would facilitate characterization of structure at different levels of detail, combine voids and solid particles in a single scheme, and provide the information necessary for making interpretations." An outline of the tentative simple scheme follows. Structure is subdivided among 7 classes and 14 subclasses. Each horizon should be described as dry, moist or wet. Numbers in brackets on the left identify the categories encountered in the present study, and the corresponding values assigned for statistical analysis.

Simple System for Describing Soil Macrostructure
(from McKeague, et al., 1986)

I Lacks an organized system of macrovoids and peds.

(1) IA The material is massive and coherent.

IB The material is loose or single-grained.

II Has a system of more-or-less vertical, tubular voids (channels) in apedal material.

IIA Channels 0.5 mm or larger in diameter occupy 0.1 to 0.5% of the volume of tubular voids can be estimated by using dot charts.

IIB Channels as specified above occupy more than 0.5% of the volume.

III A system of more or less vertical cracks traverses the horizon; horizontal planar voids are weakly-developed or absent.

IIIA The cracks occupy less than 1% of the volume and vertical

channels larger than 0.5 mm occupy less than 0.1% of the volume. (Volume of cracks can be estimated by measuring the total width of cracks in a 1 m transect; for example, four cracks 2 mm wide in 1 m would indicate crack volume of 0.8%).

IIIB The cracks occupy more than 1% of the volume or cracks occur but occupy less than 1% of the volume and channels larger than 0.5 mm occupy more than 0.1% of the volume.

IV A system of more-or-less horizontal planar voids partially or completely divides the material into platy units with less than 0.1% vertical tubular voids.

(2) IVA Planar voids are weakly expressed.

(2) IVB Planar voids are strongly expressed.

V A system of planar voids in more-or-less horizontal and vertical directions partly to completely separates the material into blocky or prismatic peds with less than 0.1% vertical tubular voids.

(3) VA The planar voids are weakly developed and the partly-formed peds adhere.

(4) VB A well developed planar void system separates most of the material into peds.

VI Vertical tubular voids occupy 0.1 to 0.5% of the volume and systems of vertical and horizontal planar voids occur.

(5) VIA Planar voids are weakly developed and the partly-formed platy, blocky or prismatic peds adhere.

(6) VIB Planar voids are well developed and most of the material occurs as peds.

VII Vertical tubular voids occupy more than 0.5% of the volume and systems of vertical and horizontal planar voids occur.

(7) VIIA Planar voids are weakly developed and the partly-formed peds adhere.

(8) VIIB Planar voids are well developed and most of the material occurs as peds.

Hand penetrometer readings were taken in the upper A horizon, the compacted layer (normally the lower A and/or upper B horizon) and in the layer below (B horizon). Note that these three layers are designated as A, AB, and B in this report. The A and B layers generally correspond to Ap and upper B horizons as used in soil classification. The AB layer may include the lower A horizon, or the upper B horizon (if the A is thin), or part of both.

Cone penetrometer readings were taken using a Dickey-John cone penetrometer at six locations approximately two metres apart on a transect centered on the pit and diagonal to obvious cultivation patterns. Readings were recorded at 8 cm intervals to a depth of 48 cm.

Similar procedures were followed for examining soils in a control area located between or adjacent to the two fields. Hand penetrometer readings were taken at similar depths to those in the field and in comparable horizons where possible.

In all fields and controls the soil was also given an overall compaction rating based on a subjective, composite assessment of the problem. This assessment evolved during the study and took into account visual evidence of compaction including layering, soil structure deformation, rooting patterns, number and continuity of pores, strength of peds, clarity and orientation of planar voids, observed differences in these characteristics between horizons, and apparent consistency of these observations from place to place within the field. The following chart (Figure 2.1) presents the main features of this subjective compaction rating scheme. Figure 2.1 shows three classes, but in the field, and for statistical analysis, 6 classes were used: none, slight, slight-moderate, moderate, moderate-severe and severe.

Compaction Indicators	Degree of Compaction: Slight	Moderate	Severe
Structure	moderate to strong granular or subangular blocky	layered, deformed	massive, structureless, clods
Consistence	very friable or friable in A horizon, friable to firm in B horizon	firm in A&B horizon	very firm in A&B horizons
Soil pores	abundance of planar and tubular pores	few tubular pores, horizontal planar voids	lack of tubular & planar pores
Root distribution	normal distribution of inped and exped roots	deformed rooting pattern	distinctive decrease in abundance in compact layer relative to layer above, root mat above compact layer
Earthworms	moderate to plentiful	few to moderate	none
Soil water	uniform moisture distribution, little or no ponding after rains	restricted water percolation	surface ponding or ponding above compact layer after rains
Uniformity	above features found at all spot checks	above features variable	most above features observed at all spot checks

Figure 2.1 Soil Compaction Indicators: Subjective Rating

2.1.2 Level II - Detailed Examinations

In addition to the transects used to determine the extent and severity of subsoil compaction in Southwestern Ontario twenty additional sites, each consisting of a field and a control were examined. Level II investigations included observations and measurements as made for level I sites plus laboratory analysis of layer A and AB samples including pH, organic matter, particle size, and nutrient levels (P, K, Mg, Ca). Bulk densities and percent moisture of each layer were measured in duplicate.

The initial plan was to measure saturated hydraulic conductivity on these sites using the Guelph permeameter. However, in three of four attempts at using the instrument, negative values for K-sat were obtained, and in one situation the water level rose in the permeameter. These difficulties were attributed to recent rains and to layering in the soil. Because of the lack of meaningful measurements, the time consuming operation (4-6 hours per site), and the near freezing conditions with the onset on winter (Nov. - Dec. 1987), further attempts at making permeability measurements were discontinued.

2.2 STATISTICAL ANALYSIS

2.2.1 Level I: Level and Extent of Compaction

A major challenge in this study was to determine how to design the survey so as to get the best statistically valid results representing a cross-section of farm management systems within the limited time available. Three main areas of concern were:

-how to best measure compaction, (trade-off: intensity of investigations vs. no. of sites);

-how to estimate its extent in an unbiased manner, (considered various statistical sampling techniques); and

-what are the main factors contributing to soil compaction, (need to examine soil types and management practices).

To ensure that the degree of compaction could be ascertained several different measurements of compaction were made: visual subjective

rating of composite factors; cone and hand penetrometer measurements; bulk density determinations; and descriptions of soil structure and porosity. After fieldwork was completed these measurements were analyzed statistically using the Pearson correlation matrix and regression analysis. It was found, as reported later, that all the compaction measurements were closely related to one another. The visual compaction rating was significantly linked to many factors considered (machinery and management as well as other soils measurements) and seemed to be the best indicator (and quickest for future application).

To establish severity of compaction, visual compaction rating, cone and hand penetrometer measurements, soil bulk density, and structure and porosity rankings were grouped into three categories reflecting increasing compaction (see Results). This showed that using compaction rating alone would, in most cases, provide the same rating as using a combination of all measurements each given the same weighting. Specifically, in the Level I transect surveys, in a total of 50 sites compaction rating alone underestimated compaction by one category at 6 sites and overestimated it by one category at 3 sites as compared to a composite rating of all measurements. These values lie within the confidence intervals determined using compaction rating alone. Likewise in the Level II detailed sites, one site was overestimated whereas another was underestimated. On the basis of this close fit and the statistical correlations it was judged that the visual compaction ratings were valid indicators of degree of compaction.

Each of the 50 field sites, 10 per transect, were then assigned a compaction rating (slight, moderate, severe) and the point transects were analyzed in accordance with procedures given by Wang (1982). Percentages of sites in each category were then multiplied by total area of clay to clay loam soils in the five counties to determine acreages within each rating.

2.2.2 Level II: Comparison of Field and Control Locations

Paired T-tests were conducted to compare field values with

control values for the following determinations: compaction rating, hand (pocket) penetrometer reading and cone penetrometer reading in the compacted (or equivalent) layer, and on hand and cone penetrometer indices calculated as follows:

Penetrometer Index (Cone or Hand) =
AB reading - A reading - B reading

This formula was used to emphasize the deviation from linearity with increasing depth. It allows a single value to indicate relative penetrometer resistance among three layers and is therefore considered to be superior to an absolute measurement of the AB layer. Note that in each layer six individual readings were taken and the mean values were then used in the calculations.

The statistical analysis package "Systat" was used for this analysis, and for all following analyses. In addition to paired T-tests, unpaired T-tests were conducted on bulk density values and soil moisture contents for each of the three layers.

The initial design of the study was such that 16 of the 20 Level II sites would fit into a designed experiment with four replicates which would test the controls vs. fields, the mode of deposition and the drainage in terms of their respective relationships to soil compaction. This necessitated attempts to locate well or imperfectly drained and poorly drained clay soils for each of till or lacustrine deposits within each of four clusters or replicates. In actual field work it was very difficult to locate moderately well or imperfectly drained lacustrine clay deposits and hence an imbalance toward poorly drained soils resulted which prevented the ANOVA from running. Therefore the analysis that was conducted consisted of a split plot design with field vs. control as the main plot and with mode of deposition as the subplot factor. These were run for the compaction rating, the cone penetrometer index, hand penetrometer readings in the compacted layer, and for bulk density in the compacted layer.

2.2.3 Comparisons Involving Level I and Level II Data

The closeness of linear relationships between variables was determined for a large number of variables on which data were collected in both Level I and Level II surveys using the Pearson correlation coefficient.

The objectives of these analyses were to determine which measured and observed soil properties are related to one another, to determine which farming practices and equipment are related, and to determine which farming practices and equipment are related to measured and observed soil properties indicative of compaction.

On the basis of the strength of these linear relationships, linear regressions were run in order to assess approximate rates of change of one variable due to changes in the other. For example, a regression of compaction rating against tractor size indicates the compaction rating is increasing with increasing tractor size. Such analyses, however, do not account for correlations and interactions between the independent variables. In addition, some multiple regressions were run with compaction indicators as dependent variables and factors which could be contributing to compaction as independent variables.

For additional comparisons of fields and controls T-tests were run for a number of compaction indicators.

Where necessary to make these analyses meaningful certain variables were ordered, ranked or grouped so as to be logical in relation to compaction. Crop rotation was organized as follows:

(Variable = Rotation)

1 = row crop

2 = row crop + grain

3 = 2 years or less in forage in five years

4 = more than 2 years in forage in five years

Crops grown in 1987 were grouped as follows: (Variable = Crop 872)

1 = forage

2 = cereal

3 = row crop

4 = silage corn or tomatoes

In this group category 4 was added as these were the only crops grown which require both harvesting equipment and hauling wagons to run on the fields, and hence result in increased loading and traffic on soil.

Photographs on the next three pages provide a sample of soil, topographic and agronomic characteristics encountered.

Photo 1. Nearly level clay soils. Fall planted barley.

Photo 2. Very gently undulating clay soils. Soybean field was being plowed.

Photo 3. Control: Fencerow between fields 1 and 2.

Photo 4. White beans on clay loam soils, gently undulating topography.

Photo 5. Recently plowed field that was in forage for five years. (Level clay soils, manure regularly applied.)

Photo 6. Example of moderate compaction in the lower Ah horizon and upper B horizon.

3.0 RESULTS

3.1 LEVEL I - AREAL EXTENT AND DEGREE OF COMPACTION

The percentage of sites observed to have compaction occurring at the three degrees of severity are reported in Table 3.1 by county (transect).

Table 3.1. Degree and Extent of Soil Compaction on Clay and Clay Loam Soils in Five Counties

Degree of Compaction	Middlesex	Lambton	Essex	Kent	Elgin	Total
	percent					
Slight	60	40	40	20	50	42
Moderate	40	50	30	40	50	42
Severe	0	10	30	40	0	16

Statistical Parameters for Data Given in Table 1

	Mean (x)	Sx	tsx (80%)	Confidence interval (80%)
Slight	42	6.6	10.1	32 - 52%
Moderate	42	3.7	5.7	36 - 48%
Severe	16	8.1	12.4	4 - 28%

This analysis indicates that compaction problems may be occurring on 48% to 68% of clay to clay loam soils in the five counties. The analysis is based on field observations of compaction rating on fifty fields on twenty-five farms. The farms were selected more or less at equidistant points along transects across large areas of clay to clay loam soils as shown on soil survey maps. Transect and detailed examination sites are shown on Figure 3.1.

Information gathered from 1986 Agricultural Statistics and soil surveys of counties was used to determine the approximate total acreages of corn and soybeans by county and the acreages of soils mapped as clays and clay loams; Table 3.2. To calculate acreages of these crops on these soils the total acreage of each

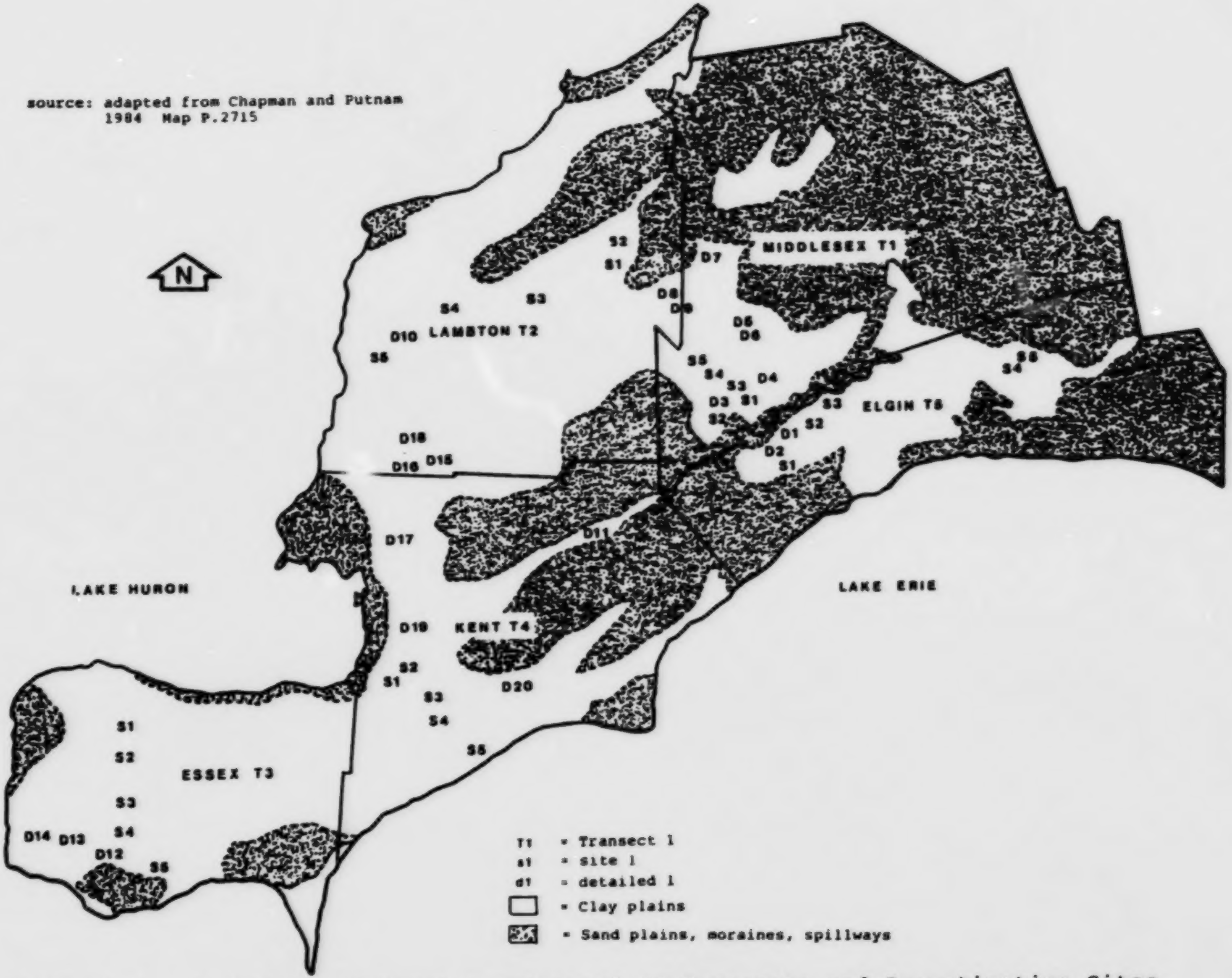


Figure 3.1. Locations of Level I and Level II Transects and Investigation Sites.

Table 3.2. Acreages of Corn and Soybeans on Clay and Clay Loam Soils in Five Counties

	Middlesex	Lambton	Essex	Kent	Elgin
Grain Corn(ac)	182,335	110,406	56,384	198,731	116,722
(bu/acre)	116	118	115	128	114
Fodder Corn(ac)	27,563	15,197	2,971	8,244	11,149
(tons/acre)	14	13.5	14	15	14
Soybeans(ac)	78,527	198,008	150,194	201,877	74,420
(bu/acre)	34	35	40	43	34
Total Acres					
All Soils	785,000	659,100	452,000	623,800	460,863
Clays	150,000	536,000	296,000	219,000	63,600
Clay Loams	190,000	20,900	40,500	101,100	81,100
Proportionate Acreages:*					
Corn/clays	40,100	101,740	38,580	72,440	17,900
Corn/clayloams	50,800	3,770	5,340	33,120	23,020
Total Corn	90,900	105,510	43,920	105,560	40.920
Soy/clay	15,000	160,390	97,630	70,660	10,420
Soy/clayloams	19,000	5,940	13,520	32,300	13,400
Total Soybeans	34,000	166,330	111,150	102,960	23,820
Corn & Soybean Clays & Clay Loams (ac)	124,900	271,840	155,070	208,520	64,740

Grand Total acres = 825,070

$$*\text{Acres Crop X } \frac{\text{Acres Specific Soils}}{\text{Acres Total Soils}} =$$ estimated acres of crop on specific soils (assuming uniform distribution of crops across all soils which probably leads to a conservative estimate).

Source: Crop data from 1986 Census Data
Soils data from Soil Survey Reports

crop in a county was multiplied by the percentage of clay/clay loam soils in the county. This assumed that corn and soybeans are equally distributed across all soil types. In the absence of specific data relating crop rotations to soil type this is the best estimate that could be made within the scope of this study. During fieldwork it was the authors' impression that there might be a higher proportion of corn and

soybeans on fine-textured soils than on others; if so, the estimates of corn and soybean acreages affected given in Table 3.2 may be low.

3.2 LEVEL II - DETAILED INVESTIGATIONS

3.2.1 Field vs. Control Locations

A summary of the results of paired T-tests conducted on important measured compaction indicators is presented in Table 3.3. Note that all variables are explained in Appendix 2.

Table 3.3. Comparisons of Control and Field Measurements

Variable	Field Mean	Control Mean	s.e.dif.	T-value	P.[1]
CR[2]	34	10	5.1	6.57	***
HPAB (kg/cm2)	33	29	2.4	2.70	**
CPAB (PSI)	213	236	24.6	1.29	ns
PIC (PSI)	115	11	24.4	6.06	***
PIH (kg/cm2)	18	1.4	5.8	4.10	***

1. * significant at P= 0.10
** significant at P= 0.05
*** significant at P= 0.01
ns not significant

2. CR - Compaction Rating
HPAB - Hand Penetrometer AB layer
CPAB - Cone Penetrometer AB layer
PIC - Cone Penetrometer Index
PIH - Hand Penetrometer Index

The results show significant differences between fields and controls for hand and cone penetrometer indices, for hand penetrometer measurements in layer AB and for the compaction rating. The cone penetrometer readings within the AB layer (below plow depth) do not indicate a clear difference. In general, conditions as measured in the fields are inferior to those in the controls.

The results of T-tests on bulk densities, soil moistures, organic matter, and pH determined in the lab are presented in Table 3.4.

Table 3.4. Comparison of Control and Field Measurements of Selected Properties

Variable	Control Mean	Field Mean	Standard error of difference	Sign. Level[1]
BD (A)g/cc[2]	1.11	1.16	.06	ns
BD (AB)g/cc	1.22	1.37	.04	***
BD (B)g/cc	1.39	1.43	.03	ns
Moisture (A) %	29.6	28.6	1.73	ns
Moisture (AB) %	27.2	27.1	1.31	ns
Moisture (B) %	22.8	24.2	1.41	ns
OM (A) %	6.1	4.1	0.64	***
OM (AB) %	4.2	3.6	0.69	ns
pH (A)	7.2	7.1	0.17	ns
pH (AB)	7.3	7.1	0.16	ns

1. *** significant at P = 0.01
ns not significant at P = 0.10

2. BD - Bulk Density
Moisture - gravimetric
OM - organic matter
pH - soil reaction

There is a highly significant difference in mean bulk densities of layer AB between controls and fields, the fields being more dense. Moisture levels were not significantly different at the time of field examination. Organic matter levels are considerably lower, 2%, in the topsoils of fields compared to controls. Soil reaction, pH, is slightly but not significantly lower in fields than controls.

Soil profile and lab data were examined carefully to ascertain that measurements reflected changes in soil properties rather than differences in sampling depths relative to positions of pedogenic horizons. Comparison of topsoil (Ap/Ah) thicknesses revealed no statistically significant difference between controls and fields. Therefore, the AB layer measurements represent differences in compaction usually within the lower Ah horizon rather than, for example, an Ah horizon in the control and an AB or B pedogenic horizon in the field. This is also supported by results of particle size analysis. In most of the sites examined there was no evidence or report of deep

cultivation whereby B horizon material could have been mixed with topsoil.

3.2.2 Analyses of Variance

Analyses of variance were conducted for the sixteen sites planned as a split plot design for CR, PIC, BDAB, and HPAB. Due to the imbalance in drainage classes it was necessary to run the analyses with only field type (field vs. control), mode of deposition (lacustrine vs till) and rep (geographic area reflecting climate) as factors. Results are given in Table 3.5.

Table 3.5. Significance of Key Compaction Measurements in the Analysis of Variance

Variable	Type	Rep	Depo	Type x Depo[1]
CR[2]	***	ns	ns	ns
HPAB	***	**	ns	ns
PIC	***	ns	ns	ns
BDAB	**	ns	ns	ns

[1] * - significant at P = 0.10
** - significant at P = 0.05
*** - significant at P = 0.01
ns - not significant

[2] CR - compaction rating
HPAB - hand penetrometer AB layer
PIC - cone penetrometer index
BDAB - bulk density AB layer

The only factors explaining significant amounts of variance in these measurements were the field type (field or control) and, hand penetrometer readings in the AB layer rep (geographic area). Mode of deposition was not important.

3.3 LEVEL I AND II COMPARISONS

3.3.1 Correlations

Two Pearson correlation matrices are presented in the appendices. The first matrix shows correlation coefficients between pairs of measured

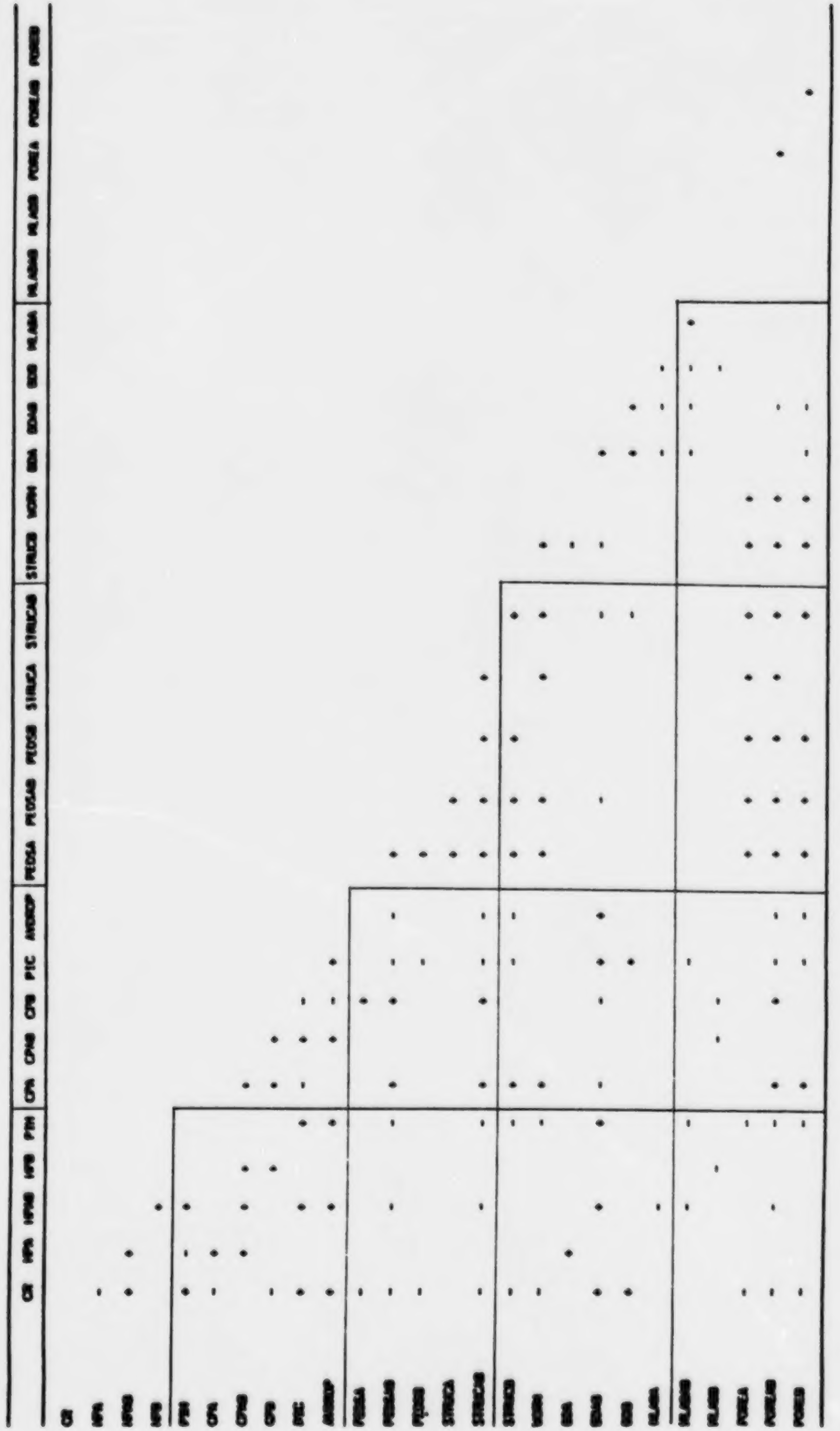
and observed variables. Table 3.6 presents a simplified version of the appendix table and shows which pairs of variables were significantly correlated ($p = 0.05$). It is evident from the correlations that the main indicators of compaction for the study, that is, CR, PIC, PIH, Pore AB, and BDAB are strongly correlated with one another.

Figure 3.2 shows the relationships between these variables with respect to classification of soils into the three compaction categories (slight, moderate, and severe). The "moderate" class was derived by obtaining the mean for each variable and extending the class limit two standard deviations to each side of the mean. The "slight" class is below the mean minus two standard deviations: the "severe" class is above the mean plus two standard deviations. This classificiation is intended as a rough guide for relating observations of the different measured and observed parameters.

There are discrepancies between using the mean plus and minus two standard deviations versus using the regression equations of compaction rating against other measurements to calculate the corresponding class limits. Graphs showing the compaction ratings plotted against bulk density AB, cone penetrometer index, hand penetrometer index and pore rating AB are given in Appendix 7. These graphs indicate a wide scatter of points and the low r values indicate that a large part of the variation is due to other factors. These probably include moisture content, textural differences, organic matter levels, cultivation history, and soil structural differences. Nevertheless, the very low probability values (less than 0.01) indicate highly significant relationships as also indicated by the Pearson correlation matrix. The question that arises then is, what is the best measure of compaction?

During field investigations it seemed that the visual subjective compaction rating made the most sense in integrating all factors, in spite of the lack of specific definitive categories, and difficulties due to excessive wetness at some sites. As part of the analysis, the separate ratings of compaction for each site (fields not controls) were tabulated to compare visual compaction rating versus composite rating. For example:

Table 3.6 Pearson Correlation Matrix for Selected Soil Properties.



+ Positive Correlation - = Negative Correlation Significant at p = 0.05

DEGREE OF COMPACTION

Compaction Indicator	SLIGHT		MODERATE		SEVERE	
Profile Compaction Rating	1 None	2 Slight	3 Slight-Moderate	4 Moderate	5 Moderate-Severe	6 Severe
Bulk Density AB (g/cc)	<1.30		(1.37)* 1.30-1.45		>1.45	
Cone Penetrometer Index 2(AB)-A-B	<2.6		(7.8) 2.6-13.1		>13.1	
Hand Penetrometer Index 2(AB)-A-B	<0.16		(1.15) 0.16-2.30		>2.30	
Pore Rating AB	>7.5		(5.1) 7.5-2.7		< 2.7	

(1.37)* mean value overall
<1.30 class numerical values (mean plus and minus 2 standard deviations)

Note: See Appendix 7 for additional statistical comparisons.

Figure 3.2. Guidelines for Quantifying Compaction Indicators for Soils Examined.

Site	Slight	Moderate	Severe	Compaction Rating[2]
	Number of Indicators in Each Category[1]			
d1		3	2	moderate
d2	4	1		slight
d3		3	2	moderate
d4		1	4	severe

[1] = equal weighting for visual compaction rating, cone penetrometer index, hand penetrometer index, bulk density, and pore rating.

[2] = visual compaction rating used in reporting degree of compaction.

This tabulation procedure yielded results similar to those developed through statistical analysis. In the detailed Level II investigations overall results are identical although compaction rating once underestimated and once overestimated the combined rating of all measurements. Similar procedures applied to the Level I transect inspections indicated that out of 50 sites compaction rating was underestimated 6 times and overestimated 3 times when compared to combined ratings. This variation tends to make the results conservative, that is, if combined ratings were used the compaction problem would be considered more serious. However, the resultant values lie within the confidence intervals expressed so adjustments were not made.

The foregoing discussion reflects the developmental nature of this project in that techniques were developed during the survey. In the future more effort to refine and objectively define the visual compaction ratings using present guidelines as a base is recommended.

The data presented in Table 3.6 indicate significant positive correlations between the observed compaction rating and main indicators discussed above, as well as, the average drop of the cone penetrometer on exiting the compaction layer, bulk density of the B layer and the soil structure observations ped strength, structure and porosity. These relationships indicate that the methods used in this study to examine soil compaction are legitimate indicators of a physical phenomenon actually occurring in the field.

The second matrix shows correlation coefficients indicating the strength of linear relationships between farming practices determined from the interviews and key observed and measured soil properties. A simplified matrix is shown in Table 3.7. It is evident from Table 3.7 that the parameter most strongly linked with measured and observed data relating to soil compaction is the horsepower of the largest tractor used on the fields, TIHP, which is significantly correlated with CR, PIH, WORM, BDAB, BDB, and PORE AB.

Both the crop grown in 1987, when ranked as described in Section 2 (CROP872), and the number of passes made were correlated with CR, POREAB and PORE B. The type of rotation used was correlated with POREAB and, in additional runs, the size of the combine was correlated only with BDAB. Of considerable interest in these correlations is the relationship existing between the number of earthworms observed (WORM) and other parameters (Farm size, rotation, TIHP CR, PIH, POREAB). Neither farm size nor the application of manure were correlated with any of the compaction indicators. In the case of manure, this could result from a very limited number of observations where manure was applied, and the fact that in two of the three instances manure was applied by irrigation.

3.3.2 Regressions

In order to estimate rates of change of dependent variables as other variables change, some linear regressions were conducted. The results are presented in Table 3.8. As an example, an increase in the first tractor horsepower (TIHP) from 100 to 300 H.P. could result in an increase in the compaction rating from 2.8 (slight to moderate) to 4.8 (moderate to severe).

Due to interdependency of many variables the use and interpretation of multiple regressions to model compaction using the data obtained did not lead to a complete or meaningful model. An example of a multiple regression conducted on four independent variables with low correlations is given on the following page:

Table 3.7. Pearson Correlation Matrix for Selected Farm Managment and Soil Properties.

	SIZE	ROTATE	CROP872	Y5CORN	Y5SOY	FCOMPAS	T1HP	T2HP	YLDEFF	MANURE	PLOW	PASSES	DEPO	CR	PIH	PIC	WORM	BDA	BDAB	BDB	MLABA	MLABA	MLABB	POREA	POREAB	POREB	CORNY87
SIZE																											
ROTATE																											
CROP872		-																									
Y5CORN																											
Y5SOY																											
FCOMPAS				+																							
T1HP	+																										
T2HP	+						+																				
YLDEFF																											
MANURE		-																									
PLOW	+	-						+																			
PASSES			+																								
DEPO		-																									
CR			+			+	+					+															
PIH							+	+						+													
PIC														+	+												
WORM	-	+					-							-	-												
BDA					-				+																		
BDAB							+							+	+	+		+									
BDB							+	+						+		+		+	+								
MLABA							-											-	-	-							
MLABAB							-								-			-	-	-	+						
MLABB						-														-							
POREA														-	-		+										
POREAB		+	-				-					-		-	-	-	+		-					+			
POREB			-			-		-				-		-	-	-	+	-	-					+	+		
CORNY87				+																							
SOY87					+										+												

+ = Positive Correlation   - = Negative Correlation   Significant at p = 0.05

Compaction Rating = -2.67 + (0.011 X primary tractor hp) + (1.04 X crop group 87) + (0.43 X geological deposit) + (0.55 X MANURE)

This would indicate the compaction rating to be increasing 1.1 units for each 100 horsepower increase of the largest tractor, increasing 1.04 units for each change of crop categories from forage to grain to row crop, to silage corn or tomatoes, increasing 0.43 units for lacustrine as opposed to till deposits, and increasing by 0.55 units if manure is not used (the benefits of increased organic matter outweigh compaction caused during spreading manure, but note that this is based on very limited data). Also note that the latter two variables although exhibiting trends, were not significant (p = 0.05). This model explained only 43% of the variation in compaction rating.

Table 3.8. Coefficients and Significance Levels of Selected Linear Regressions

Dependent Variable	Independent Variable	Constant	Coefficient	Significance
CR	TIHP	1.84	0.01	**
CR	T2HP	2.767	0.006	*
CR	WORM	4.179	-0.679	***
CR	PASSES	1.93	0.20	***
CR	CROP872	0.5	1.02	***
CORNY87	CR	155.9	-8.3	*
PIC	TIHP	2.89	0.03	*
PIC	T2HP	4.72	0.034	*
PIC	PASSES	2.79	0.74	*
PIH	TIHP	-0.144	0.009	***
PIH	T2HP	0.328	0.009	***
PIH	WORM	2.31	-0.47	***
SOY87	PIH	44.2	2.96	**
BDAB	TIHP	1.25	0.001	**
BDAB	T2HP	1.31	0.001	*
YSSOY	BDAB	1514	-1024	*

Dependent Variable = Constant + Coefficient X Independent Variable

*** - significant at P <0.01
** - significant at P <0.05
* - significant at P <0.10

3.3.3 T-Tests

The results of T-tests between field and control means of observed and measured data for both levels of the study are shown in Table 9. The results show the controls to have less compaction as indicated by all these measurements, excepting the actual cone penetrometer reading in the AB layer. The latter may be a result of the increased root mass that was evident in the controls.

3.3.4 Frequency Tables

Frequency tables of compaction rating by rotation, county, soil type, and 1987 crop are presented in Tables 3.10, 3.11, 3.12, and 3.13. The number of cases of severe compaction for rotation 2 and rotation 4 is at first alarming. However, silage corn in 1987 accounts for two of the five noted severe compaction cases for rotation 2 and for the sole occurence of severe compaction with rotation 4. Table 3.11 indicates the tendency for compaction problems to be more extreme in Kent and Essex county, and to be lessened in Elgin.

The actual number of observations for most soil types is too small to accurately determine compactability by soil type, nevertheless, Table 3.12 indicates the soil types and compaction levels encountered.

Although the number of observations for silage corn and tomatoes are few, an examination of Table 3.13 would indicate these two crops to be of major concern with respect to subsoil compaction. This is attributed to the high number of passes, including hauling wagons, and need to harvest at a critical stage in crop maturity regardless of soil moisture. Weather and resultant soil moisture conditions at harvest have a great role in the compaction that actually occurs.

Table 3.9 Comparison of Control and Field Measurements for Combined Level I and Level II Data

Measurement	Control Mean	Field Mean	s.e. (diff)	Significance
CR	1.0	3.3	0.21	***
HPAB	2.8	3.1	0.14	*
CPAB	21.5	19.3	0.92	**
PIH	0.1	1.1	0.25	***
PIC	1.1	7.8	1.30	***
POREA	7.9	7.4	0.17	***
POREAB	7.7	5.1	0.28	***
POREB	6.5	5.6	0.23	***
WORM	3.0	2.2	0.35	**

* signficant at p = 0.10
** significant at p = 0.05
*** significant at p = 0.01

CR	Compaction rating
HPAB	Hand penetrometer AB
CPAB	Cone penetrometer AB
PIH	Hand penetrometer index
PIC	Cone penetrometer index
POREA	Porosity A
POREAB	Porosity AB
POREB	Porosity B
WORM	Earthworm abundance

See Appendix 2 for numerical classes.

Table 3.10. Compaction Rating by Rotation Frequencies (Percentages, n=70)

Compaction Rating	Row Crop	Row Crop & Grain	1-2 Years in 5 in Forage	2 Years in 5 in Forage	Total
Slight	8	17	8	7	40
Moderate	17	21	4	1	43
Severe	6	9	1	1	17
TOTAL	31	47	13	9	100

Table 3.11. Compaction Rating by County Frequencies (Percentages, n=70)

Compaction Rating	County					
	Middlesex	Lambton	Essex	Kent	Elgin	Total
Slight	10	9	6	4	8	37
Moderate	10	11	7	9	9	46
Severe	1	3	6	7	0	17
TOTAL	21	23	19	20	17	100

Table 3.12. Compaction Rating by Soil Type Frequencies (Percentages, n=70)

Compaction Rating	Brantford clay loam-clay	Brookston clay	Calstor clay	Clyde clay	Haldimand clay	Miami clay loam	Napanee clay	Perth clay	Thames clay	Toledo clay	Total
Slight	10	9	7	0	3	5	1	3	0	0	38
Moderate	10	11	4	4	4	1	0	6	1	3	44
Severe	2	7	3	3	0	0	0	0	0	3	18
TOTAL	22	27	14	7	7	6	1	9	1	6	100

Table 3.13. Compaction Rating by 1987 Crop Frequencies (Percentages, n=69)

Compaction Rating	Forage	Winter Wheat	Barley	Oats	Soybeans	Corn	Silage Corn	Tomatoes	White Beans	Spring Wheat	Total
Slight	8	7	4	0	12	9	0	0	0	0	40
Moderate	0	0	1	1	16	25	0	0	1	1	45
Severe	0	1	1	0	5	1	4	3	0	0	15
TOTAL	8	8	6	1	33	35	4	3	1	1	100

3.3.5 Modifications to Areal Extent

Examination of the types of farms and size of tractors used in comparison with census data indicated this study to be skewed towards large farms and large tractors (see Table 3.14). The results of correlations conducted do not indicate a relationship existing between farm size and compaction rating. However, a strong relationship exists between tractor size and compaction rating, hence there is possibility that the aeral extent determined in Section 2 is exaggerated. On the other hand, much of the disproportion could result from a very large number of small tractors reported in the census data for many small farms with very low gross farm incomes, and many small intensive operations such as greenhouses, fruit growers, etc.

Another problem is that the census data do not relate tractor size to soil type. Since clay soils require larger tractors for cultivation than lighter soils, a higher proportion of large tractors may occur on clay soils than reflected in county averages covering all soil types. Considering these factors, it is likely that the results are not biased and are a reasonable indication of the state of compaction of clay soils in Southwestern Ontario. Improved data relating farm size and tractor size to soil type by county would improve the understanding of this situation.

Table 3.14 Comparison of Farm Acreage and Tractor Size Distribution of Study Farms Census Farms

Farm Size Class (acres)	% of Study Farms	% of Census Farms
< 70	5	37
70-239	34	40
240-559	34	15
> 560	27	3
Tractor Size (H.P.)		
< 49	8	45
50-99	45	39
100-149	23	12
> 150	23	3

4.0 DISCUSSION AND INTERPRETATION OF RESULTS

4.1 IMPACT OF SOIL COMPACTION ON SOIL LOSSES AND PHOSPHORUS DELIVERY.

4.1.1 Background

In studies conducted by PLUARG it was estimated that total P loadings to the Great Lakes from agricultural sources of the Canadian Great Lakes Basin were 3,000 T/year. About 70% of this was from cropland runoff (Miller et al. 1982). Percent clay in the surface soil and percent of land in row crops accounted for most of the variation in total P loadings. Therefore, clay soils of Southwestern Ontario, where row crops dominate, are large contributors to P loadings of the Great Lakes, in spite of the relatively flat topography.

Subsoil compaction reduces the porosity of the soil below the plow layer so it must also reduce the infiltration rate into this layer. This would therefore increase soil erosion rates, as well as losses of both dissolved and total P, in situations where the wetting front is impeded by the compacted layer sufficiently to increase soil moisture at the surface.

Although studies on the effect of subsoil compaction on erosion are rare, this effect has been noted in the literature (Fuller, 1985). A major difficulty in attempting to relate subsoil compaction and P losses is determining what proportion of runoff events and runoff volume would result from, or be increased by, compaction at depth. Numerous summer runoff events may occur as a result of high intensity storms where rainfall exceeds surface infiltration rate, and numerous winter and spring runoff events occur when the subsoil is frozen and virtually impermeable (Rudra et al., 1982). Increased P losses and runoff would occur during rainfall events that occur when the plow layer becomes saturated and the subsoil limits downward percolation. Dickinson

(Dickinson et al. 1975, Dickinson and Wall, 1977) found that the majority of soil erosion and sediment transport in Southern Ontario occurs in March, April and May. This is a period of high soil moisture in which subsoil impediments to infiltration may be critical to runoff rate. Since for the latter proportion of this period the depth of frost is well below plow depth or frost is non-existant, it is likely that soil compaction is a major factor in determining runoff volumes, erosion rates and P losses in Southwestern Ontario.

4.1.2 Magnitude in the Study Area

Determination of the magnitude of the effect of compaction on erosion and P losses is difficult. Numerous models for evaluating non-point sources of pollution have been developed (See Section 4.2 on modeling). These models are appropriate for event or daily based predictions of soil erosion and chemical loss from field or small basins, and generally require a large number of input parameters specific to the individual site being examined. They require calibration and testing in Southwestern Ontario (Rudra, et al. 1985). Most models utilize modified versions of the USLE (Universal Soil Loss Equation) to determine soil erosion rates, then add a nutrient modeling component to determine rates of nutrient losses. In determining long-term averages it is useful to examine the effect of compaction on P loadings through the use of the USLE.

The only allowance for soil compaction effecting erosion rates predicted by the USLE is through the K-factor, which can be changed according to permeability class. A sample calculation of the magnitude of this effect is as follows for soils in the study area:

Soil K determined for:

50% Silt 5%VFS %Sand 15% 4%OM

Initial K estimate = 0.19

Structure - fine granular

If permeability = mod K = 0.18

If permeability = s-mod K = 0.20

If permeability = slow K = 0.22

If permeability = v slow K = 0.25

If severe subsoil compaction reduces permeability on these soils from moderate to very slow then the following K-values apply:

No - slight compaction K = 0.18

Moderate compaction K = 0.21

Severe compaction K = 0.25

Severe compaction produces $\frac{.25-.18}{.18} \times 100 = 39\%$ increase in soil erosion

Moderate compaction produces $\frac{.21-.18}{.18} \times 100 = 17\%$ increase in soil erosion

Using the USLE with the K factors determined above, the effect of subsoil compaction on soil loss due to water erosion can be estimated. Table 4.1 shows estimated soil losses for severely compacted soils in contrast to non-compacted soils. Since the R-factor varies throughout the area erosion rates have been calculated for two values of R.

Table 4.1. Estimated Annual Soil Losses by Water Erosion on Clay - Clay Loam Soils in the Study Area (tonnes/hectare).

		Not Compacted		Severely Compacted	
		K = 0.18		K = 0.25	
		L = 200 m S = 0.5%	L = 100 m S = 2%	L = 200 m S = 0.5%	L = 100 m S = 2%
R=100	Corn	3.12	6.34	4.33	8.80
	Winter Wheat	0.92	1.86	1.28	2.59
	Forage	0.07	0.15	0.10	0.19
R=75	Corn	2.34	4.77	3.27	6.61
	Winter Wheat	0.70	1.42	0.97	1.98
	Forage	0.05	0.10	0.07	0.15

L = Slope length S = Slope R = Rainfall erosivity

Only the figure for corn on 2% slopes and severely compacted soils exceeds the soil loss tolerance value of 6.7 T/ha commonly assumed (Driver and Wall, 1982) for Southern Ontario. Soil loss per se on these soils is not a major problem, and the absolute increase in soil loss resulting from compaction is not of great concern. However, it is possible that in some conditions soil compaction may be increasing soil losses to above the tolerable rate at which productivity can be maintained indefinitely.

Due to high P delivery ratios from soils with high clay content, the P component of soil losses may be of considerably greater importance than soil losses, per se, especially from an environmental perspective.

Assuming that P losses increase in direct proportion to soil losses, possible additional P loadings resulting from subsoil compaction can be calculated.

Using acreages of clay and clay loam soils in the five counties, as shown in Table 1.2, the percentage of soils affected by compaction, shown in Table 1.1, and census data on corn and soybean area versus total area of county, the area of clay and clay loam soils affected by compaction were calculated by county. Mean P loading (kg/ha/yr) estimates derived from Miller et al.(1982) were then used to determine total loading P (kg/yr) contributed to surface waters by these soils by county. This figure was apportioned based on the extent of severely compacted, moderately compacted, and slightly compacted areas using the coefficients 1.39, 1.17 and 1.0 respectively (as determined above), and the additional P contribution resulting from compaction calculated. The values shown in Table 4.2 represent estimates of total P entering the Great Lakes as a result of soil compaction. It follows that compaction, as calculated, is responsible for about 13% of the total P entering the Great Lakes.

Table 4.2 Estimated Total P Inputs to Great Lakes Attributable to Soil Compaction.

	Middlesex	Lambton	Essex	Kent	Elgin	Total
Improved Land Clay and Clay Loam Soils (ha)[1]	96,400	171,300	100,000	108,000	42,000	
Not compacted (ha)[2]	57,800	68,500	40,000	21,600	21,000	
Moderately compacted (ha)[2]	39,000	85,700	30,000	43,200	21,000	
Severely compacted (ha)[3]	0	17,100	30,000	43,200	0	
Mean Ploading (kg/ha/yr)[3]	0.66	1.1	1.4	1.4	0.66	
Total Ploading (kg/yr)[4]	63,600	188,400	140,000	151,000	27,700	
P contribution due to moderate compaction (kg/yr)[5]	4,100	14,400	6,100	8,200	2,200	35,000
P contribution due to severe compaction (kg/yr)[5]	0	6,600	13,900	18,900	0	39,400
Total P contribution resulting from compaction (kg/yr)	4,100	21,000	20,000	27,100	2,200	74,400

Sources:

[1] Census data, 1986, and soil survey data.
[2] Tables 3.1 and 3.2.
[3] Miller et al. 1982.
[4] Improved lands (clay & clay loam) x mean P loading.
[5] Weighted contribution due to increased soil loss attributed to compaction.

Calculation procedures:

$$\text{Mean P Loading non-compacted} = \frac{a}{b+c+d} \qquad \text{(eq. 1)}$$

a = total P loading (kg/yr) per county
b = (ha non-compacted) (1.0)
c = (ha mod-compacted) (1.17)
d = (ha sev-compacted) (1.39)

P contribution due to moderate compaction =
(eq. 1) x 17% x ha moderately compacted

P contribution due to severe compaction =
(eq. 1) x 39% x ha severly compacted

Example of Middlesex County:

$$\text{Mean P loading non-compacted} = \frac{63{,}600}{(1.0\times57{,}800)+(1.17\times39{,}000)+(1.39\times0)}$$

$$= 0.615$$

P contribution due to moderate compaction = 0.615 x 0.17 x 39,000
= 4,077 kg/yr

4.2 SOIL EROSION MODELING

Numerous computer simulation models have been developed to predict soil erosion and resulting non-point source pollution. The models vary considerably in scale and in complexity of input data required. Most of the models have a basic structure as follows:

- Hydrological component - generates runoff estimates from rainfall, soil and vegetation characteristics.
- Erosion component - generates soil loss estimates from output from hydrological component as well as soil characteristics.
- Chemical component - generates losses of specific chemicals from outputs from above as well as other input data.

A summary considering the ability of some of the models to account for soil compaction is presented next.

4.2.1 CREAMS (Knisel, 1980)

CREAMS is a field scale model which allows considerable flexibility in the hydrological component. It can utilize either the USDA SCS curve number (Option 1), based on soil type, cover, management and antecedent rainfall, or the more physically based Green and Ampt equation (Option 2) in determining runoff generated from a storm. Use of the latter permits division of the soil into up to 7 layers and allows for input of the specific soil properties of hydraulic conductivity, soil porosity, bulk densities, capillary tension and water content at saturation, which are all relevant to subsoil compaction. The erosion component of CREAMS uses a modified version of the USLE which allows for further effect of soil compaction through the K factor. The model also has a nutrient component and a pesticide component. Data requirements are quite large, especially if option 2 is used. This is probably the best model to work with in the future in relation to soil compaction.

4.2.2 EPIC (Williams et al. 1982)

EPIC is a model that was derived for the purpose of assessing the effect of erosion on soil productivity, and is capable of simulating erosion over hundreds of years. The hydrological component uses SCS curve numbers and equations as its basis for generating surface runoff and is similar to Option 1 of CREAMS. However, EPIC allows division of the soil profile into up to 10 layers, and utilizes hydraulic conductivity of each layer to limit flow through the layer, increase moisture content of the layer above and increase lateral flow. It thus has a physically based means of accounting for subsoil compaction. The erosion component of EPIC is a modified version of the USLE which again allows for the K factor to change according to soil permeability. EPIC contains a nutrient component, and, in addition, models crop growth and economics. However, data requirements are very large, and this is a serious practical limitation.

4.2.3 ACTMO (Frere et al. 1975)

This is a model for both field and runoff basin size areas, which utilizes the semi-empirical infiltration concepts of the Holtan (USDAHL-70) hydrologic model. It thus provides a more physically based runoff estimate than models utilizing SCS curve numbers, and through the use of a term for "the constant rate of infiltration after prolonged wetting" can account for subsoil compaction to the extent that the above term can be estimated. Again, a modified USLE based on rill and interill components is utilized for the erosion component. The model also contains a chemical component.

4.2.4 ANSWERS (Beasley et al. 1977)

ANSWERS bears similarity to ACTMO in that it utilizes an updated Holtan hydrologic model and a version of the USLE in which the K factor can be used to account for soil compaction. It is for use on a watershed basis and does not contain a chemical component.

4.2.5 Others

AGNEPS and WIN are models recently developed in Minnesota and Wisconsin, respectively, for watershed sized areas. They both employ SCS curve numbers for generating runoff information, and use modified versions for the USLE for determining erosion. Compaction is therefore accounted for only through the K-factor, or by modifying curve numbers. The GAMES model, developed in Guelph, is similar in that the K-factor is the only factor through which subsoil compaction can be accounted for (Rudra, 1988).

A brief examination of these models indicates that CREAMS appears to be the most capable of considering the effects of soil compaction on erosion, nutrient losses and pesticide losses, and would be an appropriate tool for a closer examination of the problem in Southwestern Ontario (Dickinson, 1988). Since the model may require calibration for a broad soil type prior to use, it would be necessary to establish erosion plots on representative soils in order to validate the model. The use of CREAMS in this area could assist in the prediction of erosion, nutrient and pesticide losses, of the effect of soil compaction and structural degradation on these processes, and of the effect of ameliorative measures. It could also be used to estimate the potential impact of very large but rare storms on these losses.

4.3 CROP YIELDS AND SOIL COMPACTION

The results of the interviews indicate that farmers have a wide range of opinions as to the magnitude of the effect of soil compaction on crop yields. Farmers' estimates varied from no effect to a high of 50% reductions in yield due to subsoil compaction, with a mean value of 25%. Regression of corn yield versus compaction rating gives a 27% decrease in corn yield resulting from severe compaction (significant at $p=0.10$). These figures are based on reported yields for fields, not carefully

monitored plots; nevertheless, they are in agreement with values in the literature where a wide range of responses to soil compaction have been reported. These range from slight beneficial responses to slight to moderate compaction in topsoil under restricted soil moisture conditions where seed-soil contact is improved (Voorhas, 1977) to yield decreases of over 70% for potato yields (Flocker and Timm, 1964). Literature reporting effects of compaction on corn and soybean yields is summarized in Table 4.3. In general, reported results indicate that a 25% yield reduction as found in this study is realistic.

Causes for the yield reductions cited in the literature vary considerably, but include poor crop emergence (Schuler, 1986, Van Donan, 1959), moisture stress (Negi et al. 1980, Gautney et al. 1982, Phillips and Kirkham, 1962) and poor root zone aeration (Bateman, 1963, Blake, 1964, Phillips and Kirchen 1962, Raghaven, 1979). In addition to these factors, evidence exists that soil compaction can increase the harmful effects on corn growth of some pesticides (Martin et al. 1985).

The studies cited above were conducted in experimental field situations in which crops were planted on compacted soils at the same time as on non-compacted soils. In the Southwestern Ontario study area compacted soils would, in most years, cause delays to planting due to unfavourable moisture conditions. This could result in lower yields from a shorter effective growing season and this also reduces the choice of crops for that season.

One problem in evaluating effects of compaction is distinguishing between compaction in topsoils and subsoils. Seedling emergence, related effects and energy requirements for shallow cultivation are clearly related to topsoil conditions. Aeration, drainage, permeability, root penetration, moisture supply and, in part, nutrient supply are also strongly influenced by subsoil conditions. Based on literature and field observations it is the authors' opinion that subsoil rather than topsoil compaction becomes critically limiting for air, water or nutrient supply, or root growth and is therefore the main cause of reduced yields beyond the seed germination and emergence

Table 4.3 Summary of Impacts of Compaction on Crop Yields based on Literature Findings

Reference	Yield Reduction	Soil Type	Suggested Causes	Equipment Used	Comments	Location	Crop
Schuler, 1986	43%	clayey	- emergence	- 8T tractor + 12.5T manure spreader	- Yield reduction in 1st year only	Wisconsin	Corn
Raghavan et al. 1979	40-50%	clay	- soil-water-air relations	- contact pressures of 62, 41 & 31 KPa for 1,5,10 & 15 passes		Quebec	Corn
Fausey and Dylla, 1984	11%	silty clay loam	- fertility	- normal farming practices 1-75Mg/rear tire @ 110KPa	- reduction in yield of row beside tire track - yields recovered with added N	Ohio	Corn
Gaultney et al. 1982	50% in wet year 25% in dry year	silt loam	- moisture	- Case 1175	- very high B.D. (1.82) - affect greatest in wet year	Indiana	Corn
Erbach et al. 1986	11%	silty clay loam		- Various tractors		Iowa	Corn
Phillips & Kirkham, 1962	41% 53%	clay	- mechanical impedence - decreased oxygen	- Tractor 20 passes	- added fertilizer - normal fertilizer	Iowa	Corn
Gameda et al. 1985	56% 17%	clay loam	- delayed establishment & adverse subsoil structure	- 20T/axle		Quebec	Corn
Gray and Pope, 1986	40%	silty clay loam	- root rot	- 5T tractor	- varied with year and variety	Illinois	Soybeans
Blake, 1964	7.5% 14.5%	silt loam	- poor root adsorption - aeration		- surface compaction to 24" depth	Minnesota	Corn
Bateman, 1963	11-15 bu/ac 18-19 bu/ac 3-5 bu/ac	silty clay loam silty clay loam silt loam	- reduction in air voids	- tire traffic - 6 discings - each of above		Illinois	Corn
Nagi et al., 1980	40%	clay	- water retention properties	- 15 tractor passes	- subsoiling produced considerable improvement	Quebec	Corn
Van Doren, 1959	30%	silty clay loam	- seedling emergence	- tractor 40 psi	- surface compaction	Ohio	Corn

stages.

4.4 CAUSES OF SOIL COMPACTION

The field work and analysis from this study indicate soil compaction to be strongly linked to the size of tractor (HP) used. The number of passes made over the soil and the crop grown were also important factors in compacting the soil. Subsoil (about 15-25 cm) factors affected include: increased bulk density, increased penetrometer resistance, reduced numbers of large pores, decreased numbers of earthworms, deformed soil structure and apparent reduced permeability.

4.4.1 Axle Weight and Tires

The size of the tracks used is strongly linked to two separate factors which contribute to soil compaction. The first and most obvious of these is the pressure exerted on the soil by the tractor tires. Tractor weights were not determined, however tractor horsepower is related to weight which is in turn related to tire contact pressure, and it is well known that increased tire contact pressure leads to increased soil compaction (Amir et al., 1976, Taghavan, 1974). A second important factor is tire slippage. Davies (Davies et al., 1973) found that wheelslip was more important in causing soil compaction than wheel loading, and the effect was more pronounced for more powerful tractors, although this effect is related largely to the plow layer. An influence on subsoil could be expected under very moist conditions. Raghaven et al. 1978 also found that maximum density change per se occurred in a range of 20 to 30 percent slip. Wheel slip changes as a function of tire size, tire shape, tire flexibility, inflation pressure, wheel load, soil type, and soil strength (which varies with moisture content). Raghaven's paper, however, does not distinguish between topsoil and subsoil compaction but it is shown thaat maximum density increases under high slippage occur in the 10 to 20 cm depth range. The foregoing studies were conducted with

smaller tractors (less than 100 HP) than are commonly used in Southwestern Ontario. Results for topsoil compaction indicate that slippage is more critical than loading; however, importance of these factors in compaction of subsoils is not well defined. Also, it is not known whether heavier more powerful tractors would have the same effects.

The theoretical aspects of compaction beneath tractor tires were studied by Soehne (1958). Increased tire load results in increased depth of compaction. The effect of increased tire size, while maintaining the same tire pressure, is not directly proportional; that is, increasing tire size does not result in a proportionate decrease in depth or degree of soil compaction. The relationship is shown in Figure 4.1 (from Soehne, 1958). Dual tires spread the axle load over a much larger area than single tires, and reduce pressure within the soil below the tires at all depths (Taylor et al., 1986) for any given conditions. However, the benefits of duals in reducing compaction are questionable.

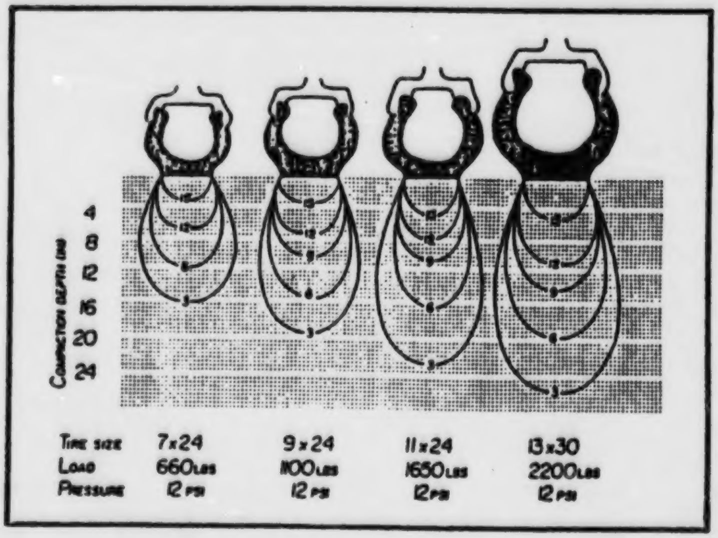


Figure 4.1 How Tractor Loads Affect Soil Compaction. (After Soehne, 1958).

First, if the total axle load is sufficient to produce subsoil compaction with duals, then the duals result in a considerable increase of the area compacted in a field. Several studies indicate reduction in intensities and depth of compaction with duals to be slight (Voorhees and Hendrick, 1977, Dickinson et al., 1979). Second, due to the duals preventing tractors from getting mired. in mud as easily, they permit operations to be conducted at higher soil moisture contents than singles would, and thereby could result in increased compaction.

Although tire inflation pressure may be a good indicator of the average pressure exerted on a soil, tire wall stiffness can result in direct transfer of much larger pressures to the soil (Vanden Berg and Gill, 1962, Larson and Gill, 1973, Chancellor, 1977). The use of tires with both lower inflation pressures and with less rigid carcasses, such as radial ply tires, could assist in reducing soil compaction.

4.4.2 Number of Passes

It is well known that increasing the number of passes will increase compaction of the soil; however, the nature of the relationship is not clear. In this study, the correlation coefficient indicating a relationship between the number of passes and soil compaction indicators shows the strength of the linear relationships. It is widely thought that each subsequent pass of a wheel produces less compaction than that of the first; that is, the relationship would not be linear. However, research by Raghavan et al. (1976) and by Ljungars (1977) shows that under some conditions compaction can increase linearly with the number of passes made for up to 6 to 18 passes. Evidence exists that extra passes increase compaction at increased depths (Vorhees, 1979), hence, limiting the number of passes may have a pronounced effect on subsoil compaction.

An alternative to limiting the number of passes may be to direct all wheel traffic onto permanent wheel tracks (Dumas et al. 1973). Rather than compacting the entire field, the farmer severely compacts a limited area which does not support crop growth Under such a system

vehicle turning areas should be restricted to specific well-defined areas, and the same wheel tracks utilized from year to year.

It is the authors' opinion that the adoption of permanent wheel tracks would aid in reducing compaction and would be feasible for operations with wide implements but not for narrow implements such as a moldboard plow. Other concerns include surface uniformity and smoothness both in terms of channeling runoff which may increase erosion and making the land rough for field operations.

4.4.3 Types of Crop Grown

The type of crop grown in 1987, when grouped and ranked as follows:

1. Forage
2. Grain
3. Row crops
4. Silage corn and tomatoes

was correlated with principal soil compaction indicators. The increasing compaction results from a combination of factors. First, the number of passes with equipment for each crop generally increases in the same order as the above listing. Forages receive little vehicle traffic, whereas tomatoes may result in over 20 passes with equipment in a year. Second, the dominant small grain is winter wheat, which receives little traffic in the late fall or early spring when moisture conditions are most conducive to soil compaction. Third, row crops require similar passes to grains but they tend to be at times when soils are prone to compaction. Finally, silage corn and tomatoes are the only crops for which the hauling equipment at harvest is consistently on the fields. Since these wagons often have heavy loads, considerable subsoil compaction may result during harvesting operations. Note too that these are perishable crops which must be harvested regardless of soil condition. Further, corn, grain and soybeans cannot be combine harvested when moisture content is too high and stocks are too soft. By the time such crops are dry soils

are less compactable.

4.5 INFLUENCE OF SOIL PARAMETERS ON COMPACTION

4.5.1 Soil Texture

Particle size distribution of a soil can influence the reduction of porosity resulting from an applied stress. In general, well-graded soils (i.e. those containing a uniform mixture of sand silt and clay) will compact to higher bulk densities and lower porosities than poorly graded soils. The theoretical particle size distribution that is most compactible lies within the sandy loam class (Larson and Allmaras, 1971). However, research indicates that the susceptibility of a soil to compaction is positively related to its clay content. Larson et al. (1980) found that the compression index (the rate of increase in soil bulk density with increases in the log of applied stress) increased nearly linearly as clay content increased to about 33%, and then remained roughly constant with further increases in clay content. Saini et al. (1984) also found compaction index to increase with clay content. The soils of the Southwestern Ontario study area contain more than 30% clay and are comparatively highly susceptible to compaction.

4.5.2 Organic Matter

In general it has been found that the higher the organic matter content of a soil the less susceptible the soil will be to compaction (Larson and Allmaras, 1971, Howard et al., 1981). It is thought that the organic matter leads to a higher strength of aggregates which prevents them from breaking apart when subjected to stress, hence preserving pore structure. Some of this effect may be lost at high moisture contents since aggregates may be weakened.

Higher organic matter levels contribute to increased earthworm populations and hence contribute to improved soil structure and porosity.

While many of the soils investigated have appreciable levels of organic matter, the decline in fields compared to fence rows could be alarming if it continues.

4.5.3 Soil Moisture

The moisture content of a soil is the property that has the greatest influence on the degree to which a soil will compact under a given pressure (Weaver, 1950, Amir et al., 1976). Soil water acts as a lubricant between soil particles and allows movement of the particles against one another at lower stresses than would occur if little moisture was present. The relationship between bulk density obtained under a given stress and soil moisture content bears a characteristic shape which is evident in Figure 4.2 (from Saini et al., 1984). There is negligible increase in bulk density with increasing moisture until moisture content is sufficient to allow slippage of soil particles. Further increases in moisture content result in rapid increases in bulk density under a given stress until a maximum is reached. This usually occurs at a moisture content near the field capacity of the soil (Akram and Kemper, 1979). Increases in moisture content beyond this level result in water occupying macropores, which then cannot be compressed due to the buoyant force of the water. Compaction is therefore reduced at very high moisture levels.

Of practical interest is the determination of the moisture content above which significant compaction will occur. The Fundy soil, a soil comparable in texture to those of the study area in the work of Saini et al. (1984) did not begin to compact until 30% moisture was reached, and maximum compaction was obtained at 38% moisture. Work to determine density-moisture relationships for soils in the study area and the establishment of guidelines for quick visual determination of critical moisture levels would be very helpful for farmers in determining when to conduct farming operations.

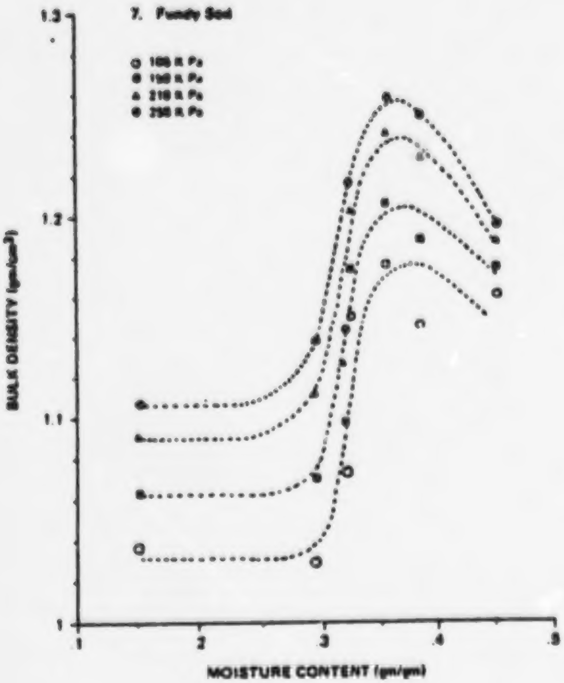


Figure 4.2. Compaction curves of Fundy soil at different moisture content. (After Saini et al., 1984).

4.6 AMELIORATION AND PREVENTION

4.6.1 Natural Processes

During the course of the field work for this study, farmers often expressed interest in the extent to which natural forces, especially freezing and thawing, reduced soil compaction. Some studies indicate that the effects of natural forces in alleviating compaction are largely restricted to surface layers. Thorud and Frissell (1976) found

the surface layer (0-15 cm) of a soil in Minnesota compacted to 1.45 g/cc to recover to a density of 1.17 g/cc in 9 years; however, compaction persisted at depths below 15 cm. In the warmer climate of South Carolina and Virginia, Hatchell and Rulston (1971) found recovery of surface soils to undisturbed densities after logging to take 18 years. In work conducted on silty clay loams in Milton, Ontario and loams in Elora, Kay et al. (1985) found that freeze-thaw cycles did not appreciably reduce bulk densities of soils compacted under zero-tillage treatments. In general, the literature indicates natural forces to be very slow in reducing subsoil compaction. The time required for noticeable reductions in subsoil compaction is too long to be practical for agricultural land uses.

4.6.2 Tillage Methods

Subsoil compaction at depths immediately below the normal plow layer may be ameliorated by tilling the soil deeper than normal. Since chisel plows require less power than moldboard plows to reach comparable depths, and since they do not bring subsoil to the surface, they are an appropriate implement for deeper tillage. Ruzel and Pitent (1987) found that fall chiselling of a silt loam in Eastern Oregon to a depth of 25 cm greatly improved infiltration characteristics of the soil as measured in November, January and April. In the current study, depth of chiselling was not determined, but chisel plowing was not found to eliminate soil compaction. Most chisel plowed soils exhibited moderate compaction. Another primary tillage implement of potential importance in ameliorating compaction is the "Paratill". (Built by the Tye Company in Texas.) The "Paratill" is an implement which has 4, 6 or 8 legs, at 50 to 100 cm spacings, coming down from a toolbar. The lower leg is oriented at a 45o angle and supports an adjustable shatter plate. As it moves through the ground it lifts the soil a couple of centimeters and shatters it from surface to a depth of about 35 cm. This improves water and air movement through the soil. In this study only one site was examined where this implement was used. The owner claimed to have had serious compaction problems in the past; however, the

field examination showed very little evidence of compaction. Such success may result from the soil moisture conditions necessary for use of the paratill as much as from the design of the implement itself. The paratill tyne has a shape similar to that of a wing, and works by lifting the soil and allowing it to shatter as it drops. It ceases to work if soil moisture is too high, therefore the operation is only conducted in dry to slightly moist soils and the chances of compacting the soil are thereby greatly reduced. Further investigation into the use of the "Paratill" is recommended.

In the use of any implement to correct subsoil compaction problems, it is important that the operation be performed when the compacted layer is dry enough to shatter the soil rather than to mold or deform it.

4.6.3 <u>Subsoiling</u>

If the compacted zone of a soil occurs below depths of cultivation by regular tillage equipment then alleviation of the problem may be accomplished through subsoiling. The literature indicates that the degree of effectiveness and the persistence of the effect of subsoiling varies considerably. Trouse et al. (1975) found subsoiling (on a sandy loam) to improve cotton production for up to five years if all traffic was withheld from the soil. Increases in traffic after subsoiling reduced the magnitude and duration of the improvement. Colwick et al. (1981) found annual subsoiling of a silty clay to be beneficial one year in five, only if traffic was controlled. The initial subsoiling effect lasted about three years. Work by Webster (1980) and by Nawrocki (1970) indicates that subsoiling may be effective for up t four years in alleviating compaction.

In summary, if subsoiling is to be effective and persistent must be performed when the soil is fairly dry, and subsequent tr over the soil should be kept to a minimum.

4.6.4 Earthworms

In the initial design of this study it was not planned to consider earthworm populations, but part way through the field work it became apparent that earthworm numbers may be related to soil compaction. Estimates of the number of earthworms encountered in the zone of compaction were then included. The correlations obtained between these estimates and farm size, size of tractor, compaction rating, hand penetrometer index and pore volume are of considerable interest. It is clear that where large numbers of earthworms exist there are few problems with soil compaction. Whether it is compaction that eliminates earthworms, or earthworms that eliminate compaction is not determined. The reduction in earthworm numbers with increasing tractor size would appear to indicate the former, and studies have shown earthworm numbers to decrease with increasing soil compaction (Bostrom, 1986). However, tractor size and farm size could be related to other factors such as the use of anhydrous ammonia or the use of pesticides which may be detrimental to earthworms.

The importance of earthworms in improving soil structure and macroporosity is well recognized (Russell, 1971, Larson and Allmaras, 1971), but to what extent earthworms can reduce existing soil compaction is not known. If the physical stresses causing compaction also reduce earthworm numbers then reducing these forces could assist in earthworm recovery, given adequate food supply. Practices such as clover plowdown could be very beneficial in this regard. Assuming that increasing earthworm abundance could help to ameliorate existing soil compaction, this becomes a promising area for research.

4.6.5 Crop Rotations

This study did not show any conclusive evidence of an effect of crop rotation on soil compaction. Although fields in forage had lower

compaction ratings than those in other crops, their inclusion in rotations did not show correlations with compaction indicators. This may result from various factors which complicate the relationship, for example, farmers who include forages in rotations would be likely to include silage corn, a crop which results in considerable compaction. Also, some farmers on wet soils may have tried alfalfa in the rotations, but had very poor stands, which, due to poor development, would not have been able to reduce compaction.

Although there is considerable work in the literature on general benefits of crop rotations, there is very little work that directly links crop rotations and subsoil compaction. Angers et al. (1987) found that tensile strength of soil aggregates and interaggregate porosity increased with time under bromegrass as did the compression index. Changes in cropping resulted in fairly rapid changes in these parameters. The results indicate that the major influences of rotations on reducing compaction may be short lived, although some residual effects may persist for many years.

It is the authors' opinion derived from field observations that forages included in rotation can have a major beneficial effect on subsoil compaction, provided that a good stand with adequate rooting is established. The persistence of the benefit is dependent upon the management of the soil subsequent to changing crop. The fencerows under grass clearly have superior soil physical characteristics.

4.7 LIMITATIONS AND WEAKNESSES

4.7.1 Limitations of Study

In spite of many significant correlations and clear results this study had some important limitations.

With regard to equipment, information about tractor horsepower was obtained but not about weights. Number of passes with equipment were

not linked to the particular tractor being used, and hence neither weight per pass, pressure per pass, or cumulative tire pressure could be utilized in determining impact of machinery on compaction. There were too few sites in the study where manure was being applied, and too much variation in method of application to be able to determine the effect of application of manure. The authors saw some sites where the use of heavy manure spreaders had resulted in considerable soil compaction and this was also frequently reported by farmers, but no link could be established statistically. Also, with regard to combines, most farmers were not able to give weights of combines used, and hence a subjective rating of size into three categories was used. Although increasing combine size did correlate with increasing bulk density in the AB layer, it did not otherwise reflect degree of compaction. A more objective and sensitive determination of combine size may have provided more meaningful results. This is of importance since numerous farmers expressed concern over the size of the combine used on their land and potential for subsoil compaction.

Several farmers mentioned that this year was generally dry and in their view not the best time to observe serious compaction. Based on literature results, natural alleviation of compaction takes several years, so that findings should have been similar in a wetter year with higher potential for compaction.

Crop yields used in this study were the farmers' estimates and not measured yields. Although most farmers probably provided excellent estimates, others understandably could give only rough approximations. Precise yields are needed to improve predictions of the impact of compaction on yields.

4.7.2 Limitations in the Literature

A review of the literature did not reveal any studies conducted on areal extent and degree of soil compaction or methods of determining

areal extent. This reflects a lack of documentation of what may be considered to be common knowledge by compaction researchers, or it may result from such studies not being reported in a manner that makes them available (i.e. as government department circulars, consultant reports, etc.).

The literature contains numerous good studies which focus on narrow specialized areas, but it is often difficult to extrapolate these to field conditions under common farming practices. Studies which consider a broader "systems" approach, taking into account field conditions, farming practices and weather patterns are urgently needed to gain a better understanding of soil compaction and its amelioration. One specific area where information is lacking and the above approach could be most helpful is in the effect of crop rotations on compaction. Long term field trials which account for varying weather patterns under each crop, the persistence of benefits from rotations, and management factors, would be of considerable practical importance.

Much of the literature on the effect of compaction on crop yields does not adequately separate surface compaction effects from subsoil compaction effects. Since surface compaction can be readily altered by common tillage operations and subsoil compaction often cannot, it is important to differentiate between the two in terms of their effects on yields, and their response to management.

Another gap in the literature occurs with respect to the impact of earthworms on compaction and vice-versa, and with regard to management practices and their effects on earthworm populations (i.e. liquid ammonia, pesticide).

As mentioned elsewhere, there is limited information on effects of subsurface compaction on surface erosion, runoff, and non-point pollution.

4.8 ECONOMIC IMPLICATIONS OF SOIL COMPACTION

This study was not intended to provide an economic analysis of the impact of soil compaction, but on the basis of results obtained some costs are clearly evident. Items 1 and 2 below represent two major costs: remaining items represent further losses but there may be considerable overlaps among these and yields, hence additional costs are not calculated. It has been reported (University of Guelph, 1978) that about half the costs of erosion are related to on-farm costs including soil losses, nutrient losses, and energy costs. The other half of the costs are off-farm and include sediment removal, water treatment, and impacts on fish and wildlife.

1. Reduced yields.
   - 12% to 25% yield reductions on moderately to severely compacted clay and clay loam soils based on estimates of yields as reported by farmers where study sites were located,
   - For corn at $3.16 (1981-86 average) per bushel this amounts to costs in the order of $13.5 million per year for the five counties studied. If similar losses are applicable to all crops grown on compacted clays and clay loams, then total costs could be around $40-45 million per year.

2. Increased soil erosion.
   - If soil is valued at about $1.50/ton (Wall and Driver, 1982) and one assumes an average soil loss of 3 tons/acre/year then rough estimates indicate that compaction increases soil losses equivalent to $0.75 to $1.75/acre/year for moderately to severely compacted clay soils. This amounts to $750,000 per year for the five counties.

3. Increased phosphorus losses.
   - From a farmer's viewpoint, the loss of P is included in the soil loss.

- There are also environmental costs for removing P from the Great Lakes for the incremental P losses attributed to compaction of clay soils in the five counties.
- Water treatment costs are increased due to increased erosion/poorer water quality.

4. Reduced effectiveness of subsurface drains.
   - Losses attributed to poorer drainage may be largely accounted for in yield reductions.

5. Increased on-farm energy requirements.
   - Increased energy used due to compaction is highly dependent on crops grown, soil conditions, equipment used, etc. As a guess, expenditures are $5-10 per acre more per year for higher fuel requirements or extra operations on moderately to severely compacted soils vs non-compacted soils. If the extra work is not done, yields may be decreased.

6. Reduced flexibility in cropping.
   - Compaction reduces soil drainage rates and may consequently delay spring field operations. This could limit the choice of crops grown or lower crop yields.

7. Costs of soil amelioration.
   - Whether mechanical (e.g. subsoiling) or biological (e.g. forage production) methods are used to alleviate compaction there is an initial increased cost. Depending on success and duration of amelioration, crop prices, and numerous other factors, the benefits may or may not be positive in the longer term.

8. Increased maintenance and removal of sediments.
   - Increased soil erosion results in increased maintenance requirements, from farm drains to highway ditches, reservoirs and harbors. The magnitude/costs are not determined at this

time.

Clearly, soil compaction represents a major cost to farmers and society in Southwestern Ontario. It is a real challenge to farmers and researchers to join forces in overcoming this problem in an economically, technically and environmentally sound manner. Urgent action is needed. Many of the factors contributing to soil compaction appear to reflect historically recent farming trends: increased acreage in row crops, increased tractor size and weight, reduction in forages, possible reduction in earthworm abundance, and reduction in soil organic matter levels. Federal and Provincial programs of the past few years to increase understanding and awareness of soil degradation and to ultimately implement degradation control practices are an encouraging start to a very serious physical, socio-economic and environmental problem.

Figures presented clearly illustrate that from a farmer's perspective the greatest cost is yield loss, therefore, it is the authors' opinion that the major thrust to alleviate soil compaction (and erosion) should focus on impacts on yields. It is noteworthy that practices to alleviate soil compaction will also generally tend to reduce soil erosion.

5.0 SUMMARY AND RECOMMENDATIONS

5.1 EXTENT AND DEGREE OF SUBSOIL COMPACTION ON SOUTHWESTERN ONTARIO CLAY SOILS.

Results of this study indicate that moderate compaction problems exist on approximately 42% of clay and clay loam soils in the study area and that severe compaction problems occur on approximately 16% of these soils. The severe problems are concentrated in Kent and Essex counties. Estimated implications of these problems are summarized as follows:

	Moderate Compaction	Severe Compaction
Yield reduction	12%	25%
Increase in soil erosion	17%	39%
Increase in P loadings to Great Lakes (kg/yr)	35,000	39,400

Correlation analysis of numerous methods of determining degree of soil compaction indicated that a visual assessment of compaction which considers layering, soil structural deformation, rooting patterns, number and continuity of pores, clarity and orientation of planar voids, observed differences in these characteristics between horizons, and apparent consistency of these observations from place to place within a field, is a useful and appropriate method for large scale studies on extent of the problem. These "qualitative" assessments can be checked with quantitative measurements including bulk density and penetrometer readings.

5.2 CONTRIBUTING FACTORS

This study revealed that the factor which makes the strongest contribution to soil compaction is the size of the tractor used in field operations. The larger the tractor as measured by horsepower, the more severe are the compaction problems created. Increased number of passes across the field also increase the degree of soil compaction. The extent to which these factors increase compaction is necessarily highly dependent upon moisture content of the soil at the time of operations.

Moisture content could not be related directly to timing of operations in this study, but its effect was reflected in the influence on the crop grown on compaction. Degree of compaction increased according to crops grown in the order; forages, small grains, row crop, and silage corn and tomatoes. This effect is a result of a combination of factors; notably, the number of passes required for the crop, the timing of cropping operations with respect to soil moisture, and the axle loads of equipment used. Results suggest that either reductions in the number of earthworms present in a soil contribute to soil compaction, or that soil compaction caused by certain operations reduces the number of earthworms present.

5.3 AMELIORATION

Literature sources indicate that natural amelioration of subsoil compaction through freeze-thaw and wetting-drying cycles is a very slow process, and is not of practical importance from an agricultural perspective. If the compacted layer occurs at depths immediately below the plow layer, tillage to below that depth using existing farm tillage equipment may be of benefit. Chisel plowing appears to be the most appropriate method for this type of amelioration. Where the compacted layer occurs at greater depths, then subsoiling could be used to alleviate the problem. The use of these methods must be undertaken at soil moisture contents dry enough to permit shattering of the soil if the desired effect is to be achieved. The length of time for which the benefits persist depends upon subsequent management practices.

Management practices which reduce the degree or extent of compaction on a field include:

1. Reduction of vehicle weights;
2. Avoidance of traffic on wet or very moist fields;
3. Limiting the number of passes over the field;
4. Restricting equipment to controlled traffic areas;

5. Utilizing cropping systems and rotations which facilitate the above and which maintain soil organic matter;
6. Reduction of tire inflation pressures. The use of duals and/or radials may permit lower inflation pressures, although the size of the reduction in compaction is questionable;
7. Utilizing practices which maintain soil flora and fauna.

5.4 RECOMMENDATIONS.

1. A refinement of the determination of areal extent and severity of subsoil compaction is advisable. The confidence intervals of the numbers determined in the present study are broad. They could be narrowed considerably through using transects within subregions of the study area. No interviews would be necessary and field work could proceed rapidly using largely visual methods of determining soil compaction as well as hand penetrometer measurements. Linkage of land use/cropping practices with soil types would be helpful; census data is too general for this purpose. More effort to refine, objectively define, and test the visual compaction ratings is highly recommended.

2. Long-term research into the effect of crop rotations on soil compaction and yield vs compaction measurements using a systems approach which accounts for variable weather under field conditions and long-term economics would assist in determining the potential benefits of rotations. Government policies or programs to support or enhance agricultural production should be designed so as to ensure that soil degradation and non-point pollution from farmlands are minimized.

3. The determination of density-moisture relationships for a limited number of soils in the survey area, and guidelines for quick hand determinations of critical moisture content would help farmers in determining when to operate their land.

4. Research to determine critical surface loadings, under varying soil moistures, which cause compaction below that penetrated by standard

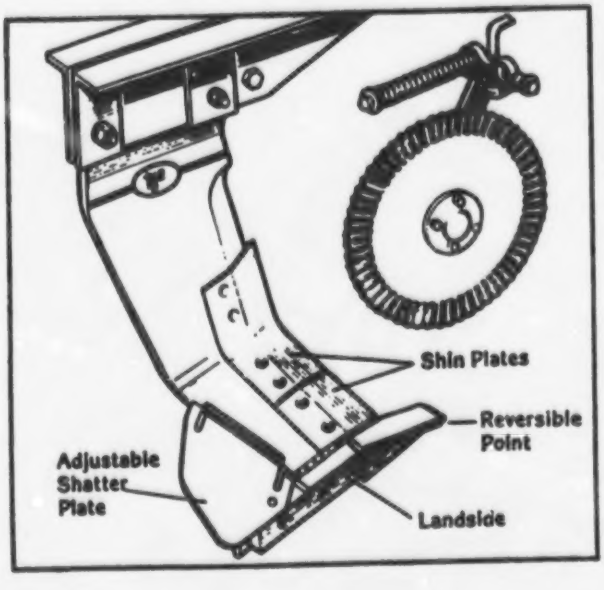
tillage equipment would aid in determining optimum size of equipment and tires.

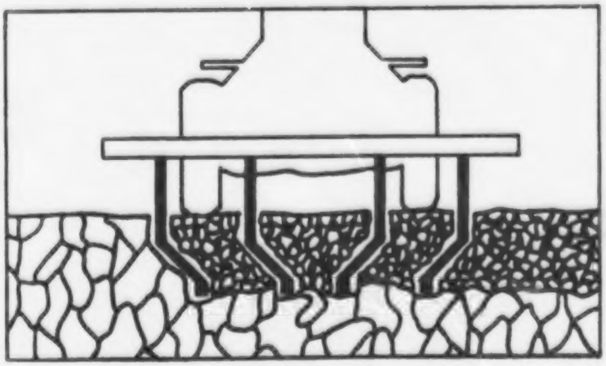
5. Research into the use of duals, radials and floatation tires as opposed to conventional tires, in practical field experiments, would be useful to farmers in determining optimum choice of tires.

6. Research into subsoiling practices considering equipment, soil conditions, timing of operations, duration, response, etc.

7. Application of the CREAMS model to conditions in the study area through field calibration could provide more accurate estimates of the effects of soil compaction on soil erosion and phosphorus losses.

8. The development of an overall model for soil compaction which would allow a farmer to estimate the effects of different cropping systems, machinery weights and tire options on compaction under varying moisture conditions could be a very useful practical tool for planning management systems. Many of the basics for such a model exist in the literature; however, integration would be necessary as well as filling in some gaps and field testing. Table 5.1 outlines a preliminary framework for such a model.





Paratill - How effective?
What conditions?
What benefits?

Table 5.1 Framework for a Model to Assist Farmers in Managing Soil Compaction.

Principal Components	Objectives	Inputs	Sources of Data
1. Soils	- determine present level of compaction, - determine soil compactibility	- texture - density - organic matter - moisture - structure	- soil surveys - field inspections - laboratory analysis - research results
2. Cropping Practices	- operations required - timing of operations - flexibility in timing	- specific crop needs - rotations - yields - fertilization	- crop manuals - farmer interviews - extension service
3. Machinery	- wheel loadings for various machines - impacts under different moisture conditions	- tire sizes, pressures - axle loads - coverage - number of passes - slippage	- machinery manuals - research results
4. Environmental	- effects on erosion/ pollution	- soil losses - runoff - nutrient losses - delivery to streams	- simulation models - field research and monitoring
5. Economics	- costs/benefits of alternative practices	- costs of operations - yields - environmental effects	- integrated research and monitoring

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NOT FOR PUBLICATION

APPENDIX 1

PEARSON CORRELATION MATRICES

APPENDIX 1

PEARSON CORRELATION MATRIX

Measured and Observed Variables

	CR	HPA	HPAB	HPB	PIH
CR	1.000				
HPA	-0.214**	1.000			
HPAB	0.255***	0.316***	1.000		
HPB	-0.081	0.134	0.322***	1.000	
PIH	0.433***	-0.233**	0.763***	-0.169	1.000
CPA	-0.421***	0.41***	0.124	0.167	-0.122
CPAB	-0.035	0.195**	0.321***	0.426***	0.121
CPB	-0.295***	0.168	0.065	0.408***	-0.193
PIC	0.454***	-0.130	0.278***	0.060	0.391***
AVDROP	0.454***	-0.016	0.310***	0.021	0.368**
PEDSA	-0.418***	0.052	-0.057	0.113	-0.161
PEDSAB	-0.565***	0.082	-0.229**	0.179	-0.371**
PEDSB	-0.258***	0.157	-0.030	0.062	-0.137
STRUCA	-0.105	-0.103	-0.148	0.099	-0.167
STRUCAB	-0.759***	0.091	-0.320***	0.103	-0.453*
STRUCB	-0.466***	0.179	-0.101	0.011	-0.201**
WORM	-0.536***	0.235	-0.185	0.115	-0.494*
BDA	0.169	0.335**	0.249	-0.178	0.168
BDAB	0.577***	0.065	0.524***	-0.127	0.552***
BDB	0.442***	-0.169	0.173	0.129	0.199
MLABA	-0.212	-0.172	-0.371**	-0.055	-0.269
MLABAB	-0.235	-0.187	-0.494***	-0.062	-0.383**
MLABB	-0.085	0.292	-0.012	-0.357**	0.004
POREA	-0.242**	-0.110	-0.167	0.131	-0.209**
POREAB	-0.829***	0.100	-0.337***	0.147	-0.492**
POREB	-0.490***	0.207	-0.097	0.029	-0.219**

	CPA	CPAB	CPB	PIC	AVDROP
CPA	1.000				
CPAB	0.631***	1.000			
CPB	0.546***	0.621***	1.000		
PIC	-0.207**	0.392***	-0.407***	1.000	
AVDROP	-0.154	0.259***	-0.319***	0.696***	1.000
PEDSA	0.157	0.149	0.217**	-0.095	-0.152
PEDSAB	0.317***	0.075	0.284***	-0.319***	-0.328**
PEDSB	0.150	-0.013	0.175	-0.265***	-0.153
STRUCA	-0.040	-0.066	0.037	-0.088	-0.050
STRUCAB	0.274***	-0.063	0.222**	-0.433***	-0.380***
STRUCB	0.256***	0.002	0.121	-0.244**	-0.192**
WORM	0.287**	0.107	0.273	-0.241	-0.142
BDA	-0.125	-0.119	-0.182	0.072	0.201
BDAB	-0.340**	-0.012	-0.360**	0.493***	0.547**
BDB	-0.233	0.160	-0.098	0.425***	0.265
MLABA	0.091	-0.067	-0.046	-0.092	-0.251
MLABAB	-0.139	-0.263	-0.104	-0.191**	-0.257
MLABB	-0.129	-0.402**	-0.365**	-0.136	0.045
POREA	0.057	0.021	0.163	-0.140	-0.117
POREAB	0.366***	0.036	0.328***	-0.447***	-0.429***
POREB	0.273***	-0.001	0.160	-0.295***	-0.215**

	PEDSA	PEDSAB	PEDSB	STRUCA	STRUCAB
PEDSA	1.000				
PEDSAB	0.322***	1.000			
PEDSB	0.287***	0.064	1.000		
STRUCA	0.199**	0.191**	0.184	1.000	
STRUCAB	0.402***	0.589***	0.299***	0.454***	1.000
STRUCB	0.296***	0.301***	0.238**	0.081	0.430***
WORM	0.378***	0.424***	0.175	0.329**	0.482***
BDA	-0.261	-0.006	-0.151	-0.078	-0.140
BDAB	-0.173	-0.312**	-0.268	-0.107	-0.451***
BDB	0.045	-0.234	-0.145	0.118	-0.375**
MLABA	-0.061	0.123	-0.091	-0.019	0.084
MLABAB	-0.044	0.154	0.166	-0.136	0.161
MLABB	-0.310	0.081	-0.200	-0.161	0.024
POREA	0.494***	0.279***	0.216**	0.902***	0.498***
POREAB	0.429***	0.733***	0.212**	0.307***	0.934***
POREB	0.352***	0.286***	0.501***	0.125	0.469***

	STRUCB	WORM	BDA	BDAB	BDB
STRUCB	1.000				
WORM	0.535***	1.000			
BDA	-0.351**	-0.101	1.000		
BDAB	-0.453***	-0.312	0.683***	1.000	
BDB	-0.103	-0.165	0.370**	0.513***	1.000
MLABA	0.268	0.105	-0.690***	-0.529***	-0.390**
MLABAB	0.207	0.157	-0.550***	-0.711***	-0.446***
MLABB	-0.283	0.048	0.070	0.133	-0.594***
POREA	0.212**	0.443***	-0.145	-0.145	0.117
POREAB	0.475***	0.543***	-0.103	-0.517***	-0.291
POREB	0.960***	0.516***	-0.352**	-0.476***	-0.134

	MLABA	MLABAB	MLABB	POREA	POREAB
MLABA	1.000				
MLABAB	0.727***	1.000			
MLABB	0.277	0.177	1.000		
POREA	-0.035	-0.133	-0.233	1.000	
POREAB	0.098	0.140	-0.093	0.427***	1.000
POREB	0.205	0.231	-0.307	0.252	0.485***

PEARSON CORRELATION MATRIX

Farming Practices and Selected Measured and Observed Variables

	SIZE	ROTATE	CROP872	Y5CORN	Y5SOY
SIZE	1.000				
ROTATE	-0.056	1.000			
CROP872	-0.062	-0.453***	1.000		
Y5CORN	-0.034	-0.046	0.065	1.000	
Y5SOY	-0.134	-0.178	0.060	0.014	1.000
FCOMPAS	0.105	0.086	0.171	0.361**	-0.156
T1HP	0.729***	-0.089	0.014	-0.268	-0.114
T2HP	0.812***	-0.121	-0.012	-0.100	-0.087
YLDEFF	0.252	-0.261	-0.109	-0.012	-0.279
MANURE	-0.110	-0.234**	0.054	0.111	0.057
PLOW	0.284**	-0.313**	-0.021	-0.079	-0.102
PASSES	0.136	-0.225	0.534***	0.249	0.064
DEPO	0.008	-0.284**	-0.030	-0.041	0.176
CR	0.113	-0.117	0.485***	-0.028	0.076
PIH	0.135	-0.213	0.137	-0.115	-0.121
PIC	0.105	-0.122	0.187	0.071	0.147
WORM	-0.284**	0.427**	-0.266	0.222	-0.025
BDA	0.195	-0.016	0.079	-0.127	-0.578**
BDAB	0.195	-0.076	0.160	0.114	-0.420
BDB	0.223	0.363	0.319	0.202	0.059
MLABA	-0.100	0.221	-0.186	-0.030	0.388
MLABAB	-0.195	0.145	-0.238	-0.139	0.431
MLABB	-0.143	-0.179	-0.358	-0.224	-0.080
POREA	0.063	0.213	-0.159	0.046	-0.166
POREAB	-0.097	0.297**	-0.496***	0.038	-0.091
POREB	-0.105	0.159	-0.472***	0.055	0.058
CORNY87	-0.004	-0.042	.	0.944***	0.322
SOY87	-0.077	-0.371	.	0.019	0.919***

	FCOMPAS	T1HP	T2HP	YLDEFF	MANURE
FCOMPAS	1.000				
T1HP	0.057	1.000			
T2HP	0.087	0.770***	1.000		
YLDEFF	-0.250	0.254	0.332	1.000	
MANURE	-0.201	-0.147	-0.160	-0.264	1.000
PLOW	0.095	0.154	0.270**	0.086	0.157
PASSES	0.060	0.176	0.097	-0.162	0.048
DEPO	-0.082	0.019	-0.089	-0.010	0.069
CR	0.349***	0.345***	0.199	-0.049	0.117
PIH	-0.075	0.325***	0.333***	0.209	-0.068
PIC	-0.092	0.218	0.227	0.209	-0.220
WORM	-0.115	-0.371**	-0.298	0.014	-0.185
BDA	0.172	0.292	0.254	0.630**	0.062
BDAB	0.341	0.491**	0.430	0.560	0.107
BDB	0.400	0.556**	0.512**	-0.089	-0.415
MLABA	-0.065	-0.492**	-0.318	-0.516	-0.172
MLABAB	-0.276	-0.494**	-0.423	-0.561	-0.073
MLABB	-0.451**	-0.346	-0.288	0.043	0.425
POREA	0.058	0.095	-0.012	0.130	-0.135
POREAB	-0.159	-0.259**	-0.187	0.161	-0.103
POREB	-0.277**	-0.234	-0.257**	-0.004	0.092
CORNY87	-0.314	0.040	0.017	-0.435	-0.061
SOY87	0.186	-0.134	-0.001	0.506	-0.170

A4

	PLOW	PASSES	DEPO	CR	PIH
PLOW	1.000				
PASSES	-0.044	1.000			
DEPO	0.012	-0.018	1.000		
CR	-0.006	0.327***	0.057	1.000	
PIH	0.082	0.136	0.154	0.433***	1.000
PIC	0.069	0.213	-0.027	0.454***	0.391***
WORM	-0.264	-0.212	0.037	-0.536***	-0.494**
BDA	0.371	0.011	-0.072	0.169	0.168
BDAB	0.103	0.053	-0.032	0.577***	0.552***
BDB	-0.332	0.102	0.101	0.442***	0.199
MLABA	0.012	-0.269	-0.337	-0.212	-0.269
MLABAB	-0.066	-0.153	-0.062	-0.235	-0.383**
MLABB	0.295	-0.158	-0.336	-0.085	0.004
POREA	-0.051	-0.093	0.154	-0.242**	-0.209**
POREAB	0.051	-0.312**	-0.026	-0.829***	-0.492**
POREB	0.013	-0.283**	0.130	-0.490***	-0.219**
CORNY87	-0.320	0.055	0.247	-0.360	-0.197
SOY87	-0.211	0.088	0.086	0.234	0.448**

	PIC	WORM	BDA	BDAB	BDB
PIC	1.000				
WORM	-0.241	1.000			
BDA	0.072	-0.101	1.000		
BDAB	0.493***	-0.312	0.683***	1.000	
BDB	0.425***	-0.165	0.370**	0.513***	1.000
MLABA	-0.092	0.105	-0.690***	-0.529***	-0.390**
MLABAB	-0.191	0.157	-0.550***	-0.711***	-0.446***
MLABB	-0.136	0.048	0.070	0.133	-0.594**
POREA	-0.140	0.443***	-0.145	-0.145	0.117
POREAB	-0.447***	0.543***	-0.103	-0.517***	-0.291
POREB	-0.295***	0.516***	-0.352**	-0.476***	-0.134
CORNY87	-0.061	0.158	0.024	0.006	0.135
SOY87	-0.036	0.286	-0.268	-0.153	-0.189

	MLABA	MLABAB	MLABB	POREA	POREAB
MLABA	1.000				
MLABAB	0.727***	1.000			
MLABB	0.277	0.177	1.000		
POREA	-0.035	-0.133	-0.233	1.000	
POREAB	0.098	0.140	-0.093	0.427***	1.000
POREB	0.205	0.231	-0.307	0.252***	0.485**
CORNY87	-0.347	-0.127	-0.152	-0.151	0.318
SOY87	0.011	0.009	-0.352	-0.079	-0.182

	POREB	CORNY87	SOY87
POREB	1.000		
CORNY87	0.212	1.000	
SOY87	0.063	.	1.000

APPENDIX 2

VARIABLES USED IN ANALYSES: CODES AND EXPLANATIONS

APPENDIX 2

Variables Used in Analyses - Codes and Explanations

LEVEL	Level of observation in study 1 = detailed 2 = transect	
COUNTY	1 = Middlesex 2 = Lambton 3 = Essex 4 = Kent 5 = Elgin	
TYPE	1 = field 2 = control	
REP	Detailed level observations were divided into 4 clusters for Analyses of variance 1 - Elgin/Middlesex 2 - Middlesex/Lambton 3 - Essex/Kent 4 - Kent/Lambton	
SIZE	Farm size, in acres	
ROTATE	Rotation used 1 = row crop 2 = row crop + grain 3 = less than 2 years in 5 in forage 4 = greater than 2 years in 5 in forage	
CROP87	The crop grown in 1987 1 = forage 3 = barley 5 = beans 7 = silage Corn 9 = white Beans	 2 = winter wheat 4 = oats 6 = corn 8 = tomatoes 10= spring Wheat
CROP872	The crop grown in 1987, revised into four categories 1 = forage 3 = row crops	 2 = grains 4 = silage corn and tomatoes
Y5CORN	Five year average for corn yields (bu/acre)	
Y5SOY	Five year average for soybean yields (bu/acre)	

CORNY87	1987 corn yield (bu/acre)
SOY87	1987 soy yield (bu/acre)
FDATE	time of fertilizer application 1 = spring 2 = fall
FMETHOD	method of fertilizer application 1 = broadcast 2 = band 3 = both
NRATE	rate of nitrogen applied - as actual N
PRATE	rate of phosphorus applied - as P2O5
TILTIME	timing of spring tillage from 1 = 1st week in April to 8 = last week in May
FCOMPAS	the farmers compaction assessment of his land 1 = slight 2 = moderate 3 = severe
PLOWNU	number of bottoms on moldboard plow
PLOWW	width of each bottom (in inches)
PLOW	type of plow 1 = moldboard 2 = chisel 3 = ridgetill 4 = paratill/paraplow 5 = disc 6 = spring tooth cultivator this variable was modified for correlation matrix to be 1 = moldboard 2 = all others
T1HP	horsepower rating of the main tractor (for primary tillage)
T1DR	drive type of the main tractor 1 = 2 wd 2 = 2 wd + duals 3 = 2 wd + assist 4 = 2 wd + assist + duals 5 = 4 wd single 6 = 4 wd + duals
T1WFL	tires weighted with fluid, main tractor 1 = yes 2 = no
T1WWTH	rear wheel width of main tractor (inches)
T1WH (inches)	rear wheel height (rim size) for main tractor

T2HP	horsepower rating of second tractor
T2DR	drive type of second tractor - as per T1DR
T2FL	tires weighted with fluid, second tractor - 1 = yes 2 = no
T2WWTH	rear tire width of second tractor, inches
T2WH	rear tire height of second tractor, inches
COMBINE	combine size 1 = small 2 = medium 3 = large
AWARE	our subjective assessment of the farmers level of awareness of compaction problems 1 = low 2 = medium 3 = high
YLDEFF	farmers assessment of yield reduction that could result from compaction - as percentage (i.e. 25% yield loss, thus increasing yield losses correspond to increasing percentages)
MANURE	was manure applied 1 = yes 2 = no
PASSES	number of passes over field with equipment
DEPO	mode of deposition 1 = till 2 = lacustrine
DRAIN	drainage class from field observation 1 = well 2 = moderately well 3 = imperfect 4 = poor
SOILTY	soil type 1 = Brantford 1 2 = Brantford 2 3 = Brantford 3 4 = Brantford 4 5 = Brookston Clay 6 = Caister Clay 7 = Clyde Clay 8 = Haldimand Clay 9 = Miami Clay loam 10 = Napanee Clay 11= Perth Clay 12 = Thames Clay 13= Toledo Clay
CR	compaction rating from field determination 1 = none 2 = slight 3 = slight - moderate 4 = moderate 5 = moderate - severe 6 = severe

MOISTA MOISTAB MOISTB
field estimates of soil moisture level in each layer
1 = dry 2 = slightly moist
3 = moist 4 = very moist
5 = wet

HPA HPAB HPB
hand penetrometer readings in each layer (kg/cm2) based on average of 6 readings per layer per profile

PIH
penetrometer index for hand penetrometer calculated as 2 X HPAB - HPA-HPB. This formula is the deviation from linearity of the increase in readings with depth.

CPA CPAB CPB
cone penetrometer readings in each layer (PSI/10 except where otherwise noted) based on average of 6 reading points 2 metres apart, usually at two depths per layer.

PIC
penetrometer index for cone penetrometer. Calculated as per PIH.

AVDROP
the average drop of the cone penetrometer (6 observations) while going from the second layer to the third layer.
Only decreases in values were included in calculations

PEDSA PEDSAB PEDSB
strength of ped separation by planar voids as described by McKeague et al (1986), simple system. By layer A, AB or B.
1 = a, weakly developed planar voids
2 = b, strongly developed planar voids

STRUCA STRUCAB STRUCB
soil structure class 1 to 7 by layer A, AB or B, as described by McKeague et al (1986), simple system.

WORM
field estimate of earthworm numbers in a 25 x 25cm square 10cm thick of the compacted layer or equivalent 1 = non to few 2 = few (<5)
3 = moderate (5-10) 4 = many (>10)

BDA BDAB BDB
bulk density (g/cc) in the layer (A, AB or B)

MLABA MLABAB MLABB

laboratory determination of soil moisture in layer from samples taken in the field (percent of dry soil weight)

POREA POREAB POREB

the classes of McKeague et al (1986) simple system ranked as follows to reflect increasing pore volume

1 = IA	2 = IVA or IVB
3 = VA	4 = VB
5 = VIA	6 = VIB
7 = VIIA	8 = VIIB

APPENDIX 3

DATA BASE

FARMING PRACTICES, MEASURED AND

OBSERVED SOIL PROPERTIES

Compaction data, 1987

site	LEVEL	COUNTY	TYPE	REP	SIZE acres	ROTATE	CROP 87	yield 87	Y5 CORN	Y5 SOY
d1	1	5	1	1	425	2	5	45	110	45
d1	1	5	2	1	425	.	.	.	.	.
d2	1	5	1	1	52	3	5	42	.	39
d2	1	5	2	1	52	.	.	.	.	.
d3	1	1	1	1	275	2	5	48	.	44
d3	1	1	2	1	275	.	.	.	.	.
d4	1	1	1	1	950	2	7	.	.	.
d4	1	1	2	1	950	.	.	.	.	.
d5	1	1	1	0	155	1	6	.	.	.
d5	1	1	2	0	155	.	.	.	.	.
d6	1	1	1	2	155	2	6	105	105	.
d6	1	1	2	2	155	.	.	.	.	.
d7	1	1	1	2	200	2	6	135	142	45
d7	1	1	2	2	200	.	.	.	.	.
d8	1	2	1	2	1050	2	7	.	.	35
d8	1	2	2	2	1050	.	.	.	.	.
d9	1	2	1	2	600	2	6	120	135	39
d9	1	2	2	2	600	.	.	.	.	.
d10	1	2	1	0	800	2	5	50	113	50
d10	1	2	2	0	800	.	.	.	.	.
d11	1	4	1	0	280	1	5	50	143	48
d11	1	4	2	0	280	.	.	.	.	.
d12	1	3	1	3	1100	2	2	60	110	48
d12	1	3	2	3	1100	.	.	.	.	.
d13	1	3	1	3	225	2	5	48	.	41
d13	1	3	2	3	225	.	.	.	.	.
d14	1	3	1	3	104	1	5	62	150	60
d14	1	3	2	3	104	.	.	.	.	.
d15	1	2	1	4	400	2	6	175	175	52
d15	1	2	2	4	400	.	.	.	.	.
d16	1	2	1	4	400	1	6	175	165	52
d16	1	2	2	4	400	.	.	.	.	.
d17	1	4	1	4	96	1	6	160	161	999
d17	1	4	2	4	96	.	.	.	.	.
d18	1	2	1	4	250	1	5	45	.	39
d18	1	2	2	4	250	.	.	.	.	.
d19	1	4	1	0	1200	1	8	20	.	50
d19	1	4	2	0	1200	.	.	.	.	.
d20	1	4	1	3	200	2	5	54	125	51
d20	1	4	2	3	200	.	.	.	.	.
t1s1	2	1	1	0	275	2	5	45	118	44
t1s1	2	1	1	0	275	2	3	50	125	40
t1s1	2	1	2	0	275	.	.	.	.	.
t1s2	2	1	1	0	1400	1	9	1.5	157	.
t1s2	2	1	1	0	1400	2	3	80	163	40
t1s2	2	1	2	0	1400	.	.	.	.	.
t1s3	2	1	1	0	200	4	1	.	.	.
t1s3	2	1	1	0	200	2	6	130	120	40
t1s3	2	1	2	0	200	.	.	.	.	.
t1s4	2	1	1	0	1000	2	6	120	143	40
t1s4	2	1	1	0	1000	3	1	6	137	36
t1s4	2	1	2	0	1000	.	.	.	.	.
t1s5	2	1	1	0	400	1	6	140	130	48
t1s5	2	1	1	0	400	3	4	.	148	33
t1s5	2	1	2	0	400	.	.	.	.	.

Compaction data, 1987

site	LEVEL	COUNTY	TYPE	REP	SIZE acres	ROTATE	CROP 87	yield 87	Y5 CORN	Y5 SOY
t2s1	2	2	1	0	200	3	1	.	90	.
t2s1	2	2	1	0	200	1	5	40	100	40
t2s1	2	2	2	0	200	.	.	.	.	.
t2s2	2	2	1	0	170	4	1	3	120	.
t2s2	2	2	1	0	170	2	6	140	150	.
t2s2	2	2	2	0	170	.	.	.	.	.
t2s3	2	2	1	0	1500	2	3	75	110	35
t2s3	2	2	1	0	1500	2	10	40	.	38
t2s3	2	2	2	0	1500	.	.	.	.	.
t2s4	2	2	1	0	145	3	2	52	.	38
t2s4	2	2	1	0	145	3	5	48	.	48
t2s4	2	2	2	0	145	.	.	.	.	.
t2s5	2	2	1	0	400	3	6	110	105	.
t2s5	2	2	1	0	400	3	6	110	108	.
t2s5	2	2	2	0	400	.	.	.	.	.
t3s1	2	3	1	0	1100	4	6	160	165	.
t3s1	2	3	1	0	1100	2	2	70	.	.
t3s1	2	3	2	0	1100	.	.	.	.	.
t3s2	2	3	1	0	50	2	2	70	170	48
t3s2	2	3	1	0	50	2	6	145	138	50
t3s2	2	3	2	0	50	.	.	.	.	.
t3s3	2	3	1	0	125	2	5	35	.	30
t3s3	2	3	1	0	125	2	5	50	.	43
t3s3	2	3	2	0	125	.	.	.	.	.
t3s4	2	3	1	0	390	2	3	22	.	33
t3s4	2	3	1	0	390	2	5	30	85	30
t3s4	2	3	2	0	390	.	.	.	.	.
t3s5	2	3	1	0	450	4	7	135	122	.
t3s5	2	3	1	0	450	4	1	.	.	.
t3s5	2	3	2	0	450	.	.	.	.	.
t4s1	2	4	1	0	400	1	5	59	165	53
t4s1	2	4	1	0	400	1	5	59	110	51
t4s1	2	4	2	0	400	.	.	.	.	.
t4s2	2	4	1	0	100	1	8	19	.	50
t4s2	2	4	1	0	100	1	5	50	.	50
t4s2	2	4	2	0	100	.	.	.	.	.
t4s3	2	4	1	0	100	2	5	60	100	53
t4s3	2	4	1	0	100	2	6	130	127	50
t4s3	2	4	2	0	100	.	.	.	.	.
t4s4	2	4	1	0	620	2	5	50	125	43
t4s4	2	4	1	0	620	2	5	50	125	43
t4s4	2	4	2	0	620	.	.	.	.	.
t4s5	2	4	1	0	475	1	5	40	.	36
t4s5	2	4	1	0	475	2	6	140	140	35
t4s5	2	4	2	0	475	.	.	.	.	.
t5s1	2	5	1	0	600	1	6	100	100	.
t5s1	2	5	1	0	600	1	6	100	100	.
t5s1	2	5	2	0	600	.	.	.	.	.
t5s2	2	5	1	0	450	2	6	100	100	35
t5s2	2	5	1	0	450	4	5	30	.	35
t5s2	2	5	2	0	450	.	.	.	.	.
t5s3	2	5	1	0	300	3	2	60	100	43
t5s3	2	5	1	0	300	3	6	100	100	.
t5s3	2	5	2	0	300	.	.	.	.	.
t5s4	2	5	1	0	100	1	5	44	110	44

Compaction data, 1987

site	LEVEL	COUNTY	TYPE	REP	SIZE acres	ROTATE	CROP 87	yield 87	Y5 CORN	Y5 SOY
t5s4	2	5	1	0	100	1	6	110	110	.
t5s4	2	5	2	0	100	.	.	.	.	.
t5s5	2	5	1	0	160	2	6	120	120	35
t5s5	2	5	1	0	160	2	5	40	120	39
t5s5	2	5	2	0	160	.	.	.	.	.

Compaction data, 1987

site	Y5 GRAIN	Y5 other	F DATE	F METHOD	N RATE	P RATE	TIL TIME	FCOMP AS	PLOW NU	PLOW W
d1	60	999	1	1	16	64	6	1	5	18
d1	.	.	.	.	.	.	.	.	.	.
d2	80	.	0	0	0	0	6	2	4	14
d2	.	.	.	.	.	.	.	.	.	.
d3	75	999	1	1	.	.	5	2	0	0
d3	.	.	.	.	.	.	.	.	.	.
d4	55	999	0	0	0	0	5	4	7	18
d4	.	.	.	.	.	.	.	.	.	.
d5	.	.	.	.	.	.	3	.	6	16
d5	.	.	.	.	.	.	.	.	.	.
d6	.	.	1	3	75	35	4	1	4	16
d6	.	.	.	.	.	.	.	.	.	.
d7	78	999	1	3	150	50	4	1	5	16
d7	.	.	.	.	.	.	.	.	.	.
d8	65	wb22	1	3	.	.	5	3	11	14
d8	.	.	.	.	.	.	.	.	.	.
d9	60	999	1	1	134	12	5	1	5	16
d9	.	.	.	.	.	.	.	.	.	.
d10	75	999	1	3	14	21	5	2	0	0
d10	.	.	.	.	.	.	.	.	.	.
d11	999	999	1	2	164	.	4	1	0	0
d11	.	.	.	.	.	.	.	.	.	.
d12	65	t22	0	0	0	0	.	2	0	0
d12	.	.	.	.	.	.	.	.	.	.
d13	60	999	1	1	10	40	5	4	.	16
d13	.	.	.	.	.	.	.	.	.	.
d14	999	p2.75	1	1	15	60	5	4	0	0
d14	.	.	.	.	.	.	.	.	.	.
d15	85	999	1	3	214	91	3	1	5	16
d15	.	.	.	.	.	.	.	.	.	.
d16	999	999	1	3	214	91	3	1	5	16
d16	.	.	.	.	.	.	.	.	.	.
d17	999	999	1	3	228	21	5	1	5	16
d17	.	.	.	.	.	.	.	.	.	.
d18	999	999	1	1	16	64	4	1	0	0
d18	.	.	.	.	.	.	.	.	.	.
d19	999	t20	1	1	80	90	4	2	5	14
d19	.	.	.	.	.	.	.	.	.	.
d20	80	999	0	0	0	0	5	2	5	14
d20	.	.	.	.	.	.	.	.	.	.
t1s1	70	999	1	1	0	38	7	2	4	14
t1s1	50	999	1	3	55	40	3	2	4	14
t1s1	.	.	.	.	.	.	.	.	.	.
t1s2	999	wb1.5	1	3	160	117	8	1	0	0
t1s2	80	999	1	1	47	60	4	1	0	0
t1s2	.	.	.	.	.	.	.	.	.	.
t1s3	999	999	0	0	0	0	0	2	4	14
t1s3	95	999	1	1	120	55	.	2	4	14
t1s3	.	.	.	.	.	.	.	.	.	.
t1s4	72	999	1	3	103	159	4	2	5	16
t1s4	73	f6	1	3	103	159	0	2	0	0
t1s4	.	.	.	.	.	.	.	.	.	.
t1s5	999	999	1	1	200	0	5	1	5	16
t1s5	999	999	1	1	.	.	4	1	5	16
t1s5	.	.	.	.	.	.	.	.	.	.

Compaction data, 1987

site	Y5 GRAIN	Y5 other	F DATE	F METHOD	N RATE	P RATE	TIL TIME	FCOMP AS	PLOW NU	PLOW W
t2s1	999	f6	1	1	12	48	5	2	6	16
t2s1	999	999	1	2	12	48	5	2	6	16
t2s1	.	.	.	.	.	.	.	.	.	.
t2s2	999	f5	1	1	5	28	5	1	5	16
t2s2	70	999	1	1	170	70	5	1	5	16
t2s2	.	.	.	.	.	.	.	.	.	.
t2s3	75	999	1	1	20	80	1	2	0	0
t2s3	55	wb1.5	1	1	50	64	4	2	0	0
t2s3	.	.	.	.	.	.	.	.	.	.
t2s4	56	rc	3	1	80	58	8	2	4	14
t2s4	60	rc	0	0	0	0	5	2	4	14
t2s4	.	.	.	.	.	.	.	.	.	.
t2s5	50	f0	1	3	101	24	4	3	5	16
t2s5	999	f3.5	1	3	101	24	4	3	5	16
t2s5	.	.	.	.	.	.	.	.	.	.
t3s1	999	f6.25	1	3	12	48	3	2	8	16
t3s1	70	sc170	1	1	56	0	0	2	0	0
t3s1	.	.	.	.	.	.	.	.	.	.
t3s2	75	999	1	1	24	96	8	2	2	14
t3s2	70	999	1	2	24	96	4	2	2	14
t3s2	.	.	.	.	.	.	.	.	.	.
t3s3	.	.	0	0	0	0	8	2	6	14
t3s3	.	.	0	0	0	0	8	2	6	14
t3s3	.	.	.	.	.	.	.	.	.	.
t3s4	22	sc11t	1	1	74	35	4	3	0	0
t3s4	48	999	1	1	138	91	4	3	0	0
t3s4	.	.	.	.	.	.	.	.	.	.
t3s5	999	f8	1	3	111	52	5	3	5	16
t3s5	999	999	3	1	0	75	.	1	0	0
t3s5	.	.	.	.	.	.	.	.	.	.
t4s1	999	999	0	0	0	0	5	2	6	12
t4s1	999	999	0	0	0	0	5	2	6	12
t4s1	.	.	.	.	.	.	.	.	.	.
t4s2	999	t19	1	1	114	6.5	7	2	5	16
t4s2	999	999	2	1	2	6.5	7	2	5	16
t4s2	.	.	.	.	.	.	.	.	.	.
t4s3	75	999	2	1	0	65	5	1	4	12
t4s3	70	999	1	3	150	80	5	1	4	12
t4s3	.	.	.	.	.	.	.	.	.	.
t4s4	83	999	0	0	0	0	5	2	5	14
t4s4	83	999	0	0	0	0	5	2	5	14
t4s4	.	.	.	.	.	.	.	.	.	.
t4s5	999	999	0	0	0	0	5	2	0	0
t4s5	90	999	1	2	143	80	5	2	0	0
t4s5	.	.	.	.	.	.	.	.	.	.
t5s1	999	999	1	2	30	30	4	2	0	0
t5s1	999	999	1	2	30	30	4	2	0	0
t5s1	.	.	.	.	.	.	.	.	.	.
t5s2	60	999	1	3	35	35	5	1	5	14
t5s2	999	999	0	0	0	0	5	1	5	14
t5s2	.	.	.	.	.	.	.	.	.	.
t5s3	60	999	1	1	100	0	7	2	4	16
t5s3	999	999	1	3	69	15	7	2	4	16
t5s3	.	.	.	.	.	.	.	.	.	.
t5s4	.	.	1	1	12	48	5	1	4	16

Compaction data, 1987

site	Y5 GRAIN	Y5 other	F DATE	F METHOD	N RATE	P RATE	TIL TIME	FCOMP AS	PLOW NU	PLOW W
t5s4	.	.	1	3	183	208	5	1	4	16
t5s4	.	.	.	.	.	.	.	.	.	.
t5s5	40	t22	1	3	176	7	5	1	4	20
t5s5	60	.	0	0	0	0	5	1	4	20
t5s5	.	.	.	.	.	.	.	.	.	.

Compaction data, 1987

site	T1HP	T1DR	T1WFL	T1WWTH	T1WH	T2HP	T2DR	T2WFL	T2WWTH	T2WH
d1	200	5	1	23	30	150	2	1	20.8	38
d1	.	.	.	.	.	.	.	.	.	.
d2	120	2	1	18.4	34	55	2	1	15.5	34
d2	.	.	.	.	.	.	.	.	.	.
d3	120	5	2	18.4	38	70	1	2	16	38
d3	.	.	.	.	.	.	.	.	.	.
d4	180	5	1	18.4	42	150	2	1	18.4	38
d4	.	.	.	.	.	.	.	.	.	.
d5	180	6	.	18.4	42	100	1	2	.	.
d5	.	.	.	.	.	.	.	.	.	.
d6	85	5	1	18.2	36	0	0	0	0	0
d6	.	.	.	.	.	.	.	.	.	.
d7	135	1	1	20.8	38	65	1	1	16.9	34
d7	.	.	.	.	.	.	.	.	.	.
d8	300	6	2	20.8	38	200	2	1	20.8	38
d8	.	.	.	.	.	.	.	.	.	.
d9	160	2	1	20.4	38	85	3	2	15.5	38
d9	.	.	.	.	.	.	.	.	.	.
d10	140	6	2	18.4	38	155	2	1	20.8	38
d10	.	.	.	.	.	.	.	.	.	.
d11	95	3	2	18.4	38	0	0	0	0	0
d11	.	.	.	.	.	.	.	.	.	.
d12	225	6	2	20.8	38	150	2	1	20.8	38
d12	.	.	.	.	.	.	.	.	.	.
d13	60	2	2	15.5	38	45	1	1	13.6	28
d13	.	.	.	.	.	.	.	.	.	.
d14	90	2	1	18.4	30	60	1	2	16.4	28
d14	.	.	.	.	.	.	.	.	.	.
d15	145	2	2	18.4	38	75	2	2	15.5	38
d15	.	.	.	.	.	.	.	.	.	.
d16	145	2	2	18.4	38	75	2	2	15.5	38
d16	.	.	.	.	.	.	.	.	.	.
d17	100	1	1	18	38	55	1	2	15	38
d17	.	.	.	.	.	.	.	.	.	.
d18	85	2	1	14	38	30	1	2	12	38
d18	.	.	.	.	.	.	.	.	.	.
d19	225	6	1	18.4	34	140	1	1	18.4	38
d19	.	.	.	.	.	.	.	.	.	.
d20	110	2	2	18.4	34	65	5	2	16	30
d20	.	.	.	.	.	.	.	.	.	.
t1s1	110	2	2	18.4	38	70	2	1	15.5	38
t1s1	110	2	2	18.4	38	70	2	1	15.5	38
t1s1	.	.	.	.	.	.	.	.	.	.
t1s2	210	6	2	20.8	38	225	2	2	18.4	38
t1s2	210	6	2	20.8	38	225	2	2	18.4	38
t1s2	.	.	.	.	.	.	.	.	.	.
t1s3	100	2	2	18.4	38	0	0	0	0	0
t1s3	100	2	2	18.4	38	0	0	0	0	0
t1s3	.	.	.	.	.	.	.	.	.	.
t1s4	140	6	2	20.8	38	140	2	2	18.4	38
t1s4	140	6	2	20.8	38	140	2	2	18.4	38
t1s4	.	.	.	.	.	.	.	.	.	.
t1s5	160	2	1	20.8	38	80	1	2	18.4	34
t1s5	160	2	1	20.8	38	80	1	2	18.4	34
t1s5	.	.	.	.	.	.	.	.	.	.

Compaction data, 1987

site	T1HP	T1DR	T1WFL	T1WWTH	T1WH	T2HP	T2DR	T2WFL	T2WWTH	T2WH
t2s1	165	2	1	22.5	38	80	1	2	18.4	32
t2s1	165	2	1	22.5	38	80	1	2	18.4	32
t2s1	.	.	.	.	.	.	.	.	.	.
t2s2	150	2	2	20.4	48	125	1	2	18.4	38
t2s2	150	2	2	20.4	48	125	1	2	18.4	38
t2s2	.	.	.	.	.	.	.	.	.	.
t2s3	250	6	2	20.4	34	190	2	1	20.9	38
t2s3	250	6	2	20.4	34	190	2	1	20.9	38
t2s3	.	.	.	.	.	.	.	.	.	.
t2s4	95	2	1	18.4	38	60	2	2	16.9	30
t2s4	2	1	1	18.4	38	60	2	2	16.9	30
t2s4	.	.	.	.	.	.	.	.	.	.
t2s5	175	2	1	20.8	38	90	2	1	18.4	34
t2s5	175	2	1	20.8	38	90	2	1	18.4	34
t2s5	.	.	.	.	.	.	.	.	.	.
t3s1	210	6	2	20.8	38	135	2	1	20.8	38
t3s1	210	6	2	20.8	38	135	2	1	20.8	38
t3s1	.	.	.	.	.	.	.	.	.	.
t3s2	50	1	2	13	24	0	0	0	0	0
t3s2	50	1	2	13	24	0	0	0	0	0
t3s2	.	.	.	.	.	.	.	.	.	.
t3s3	125	2	1	18.4	34	45	1	1	10.5	36
t3s3	125	2	1	18.4	34	45	1	1	10.5	36
t3s3	.	.	.	.	.	.	.	.	.	.
t3s4	150	2	1	20.8	38	70	1	2	15.5	38
t3s4	150	2	1	20.8	38	70	1	2	15.5	38
t3s4	.	.	.	.	.	.	.	.	.	.
t3s5	150	2	1	20.1	38	96	2	2	18.4	36
t3s5	150	2	1	20.1	38	96	2	2	18.4	36
t3s5	.	.	.	.	.	.	.	.	.	.
t4s1	180	2	2	28	42	65	2	2	15.5	38
t4s1	180	2	2	28	42	65	2	2	15.5	38
t4s1	.	.	.	.	.	.	.	.	.	.
t4s2	115	2	2	18.4	38	55	1	2	14	38
t4s2	115	2	2	18.4	38	55	1	2	14	38
t4s2	.	.	.	.	.	.	.	.	.	.
t4s3	90	6	2	16.5	38	50	1	2	14	38
t4s3	90	6	2	16.5	38	50	1	2	14	38
t4s3	.	.	.	.	.	.	.	.	.	.
t4s4	125	2	2	18.4	38	135	2	2	18.4	38
t4s4	125	2	2	18.4	38	135	2	2	18.4	38
t4s4	.	.	.	.	.	.	.	.	.	.
t4s5	165	2	2	20.8	38	150	2	2	18.4	38
t4s5	165	2	2	20.8	38	150	2	2	18.4	38
t4s5	.	.	.	.	.	.	.	.	.	.
t5s1	160	2	1	24.5	32	130	2	1	18.4	38
t5s1	160	2	1	24.5	32	130	2	1	18.4	38
t5s1	.	.	.	.	.	.	.	.	.	.
t5s2	115	2	1	20.8	38	30	1	1	12	38
t5s2	115	2	1	20.8	38	30	1	1	12	38
t5s2	.	.	.	.	.	.	.	.	.	.
t5s3	110	2	1	18	38	60	1	1	16	34
t5s3	110	2	1	18	38	60	1	1	16	34
t5s3	.	.	.	.	.	.	.	.	.	.
t5s4	125	1	2	18.4	38	85	1	2	20.8	34

Compaction data, 1987

site	T1HP	T1DR	T1WFL	T1WWTH	T1WH	T2HP	T2DR	T2WFL	T2WWTH	T2WH
t5s4	125	1	2	18.4	38	85	1	2	20.8	34
t5s4	.	.	.	.	.	.	.	.	.	.
t5s5	160	3	2	20.8	38	60	1	2	16	34
t5s5	160	3	2	20.8	38	60	1	2	16	34
t5s5	.	.	.	.	.	.	.	.	.	.

Compaction data, 1987

site	COMBIN SIZE	AWARE	YLD EFF	MANURE	PLOW	PASSES	DEPO	DRAIN	SOIL TY	CR
d1	3	2	999	2	1	7	1	2	8	4
d1	.	.	.	.	.	.	1	2	8	1
d2	2	3	25	1	1	7	1	4	5	2
d2	.	.	.	.	.	.	1	4	5	1
d3	3	3	30	2	2	8	2	4	3	4
d3	.	.	.	.	.	.	2	4	3	1
d4	3	1	999	1	1	6	2	3	1	6
d4	.	.	.	.	.	.	2	3	1	1
d5	.	2	.	2	1	.	2	4	2	4
d5	.	.	.	.	.	.	2	4	2	1
d6	3	2	20	2	1	8	2	4	2	3
d6	.	.	.	.	.	.	2	4	2	1
d7	1		999	1	1	9	2	3	1	2
d7	.	.	.	.	.	.	2	3	1	1
d8	3	2	20	1	1	10	1	4	5	6
d8	.	.	.	.	.	.	1	4	5	1
d9	2		30	2	1	9	1	3	11	3
d9	.	.	.	.	.	.	1	4	11	1
d10	3	3	25	2	4	8	1	4	6	1
d10	.	.	.	.	.	.	1	4	6	1
d11	3	3	50	2	3	4	2	2	12	3
d11	.	.	.	.	.	.	2	2	12	1
d12	3	3	50	2	5	4	2	4	13	6
d12	.	.	.	.	.	.	2	4	13	1
d13	2	3	999	2	1	9	1	4	5	3
d13	.	.	.	.	.	.	1	4	5	1
d14	2	2	999	2	2	7	1	4	11	3
d14	.	.	.	.	.	.	1	4	11	1
d15	2	3	999	2	1	8	2	2	13	3
d15	.	.	.	.	.	.	2	2	13	1
d16	2	3	999	2	1	8	1	4	5	3
d16	.	.	.	.	.	.	1	4	5	1
d17	3	1	0	2	1	8	2	4	7	4
d17	.	.	.	.	.	.	2	3	7	1
d18	2	2	999	2	6	6	1	4	6	2
d18	.	.	.	.	.	.	1	4	6	1
d19	3	3	25	2	1	21	1	4	5	5
d19	.	.	.	.	.	.	1	4	5	1
d20	2	2	50	1	1	7	1	4	10	1
d20	.	.	.	.	.	.	1	4	10	1
t1s1	2	3	20	2	1	6	2	2	1	4
t1s1	2	3	20	2	1	7	2	3	1	2
t1s1	.	.	.	.	.	.	2	2	1	1
t1s2	3	2	20	2	5	10	2	2	4	4
t1s2	3	2	20	2	6	5	2	2	4	2
t1s2	.	.	.	.	.	.	2	3	4	1
t1s3	0	2	0	2	1	5	2	3	3	2
t1s3	3	2	0	2	1	5	2	3	3	2
t1s3	.	.	.	.	.	.	2	3	3	1
t1s4	3	2	50	2	1	6	2	3	3	4
t1s4	3	2	50	1	1	4	2	3	3	1
t1s4	.	.	.	.	.	.	2	2	3	1
t1s5	2	2	999	2	1	6	2	3	1	2
t1s5	2	2	999	2	1	6	2	3	1	4
t1s5	.	.	.	.	.	.	2	2	1	1

Compaction data, 1987

site	COMBIN SIZE	AWARE	YLD EFF	MANURE	PLOW	PASSES	DEPO	DRAIN	SOIL TY	CR
t2s1	0	2	999	2	1	5	1	4	11	2
t2s1	2	2	999	2	1	6	1	4	11	4
t2s1	.	.	.	.	.	.	1	4	11	1
t2s2	0	2	50	1	1	5	1	3	11	1
t2s2	2	2	50	2	1	5	1	3	11	3
t2s2	.	.	.	.	.	.	1	3	11	1
t2s3	2	2	40	2	2	6	1	4	5	4
t2s3	2	2	40	2	6	6	1	4	5	3
t2s3	.	.	.	.	.	.	1	4	5	1
t2s4	3	2	0	2	1	6	1	3	6	2
t2s4	3	2	0	2	1	7	1	4	6	1
t2s4	.	.	.	.	.	.	1	3	6	1
t2s5	3	3	999	2	1	6	1	4	6	6
t2s5	3	3	999	2	1	6	1	4	6	4
t2s5	.	.	.	.	.	.	1	4	6	1
t3s1	3	2	5	2	1	6	1	4	5	4
t3s1	3	2	5	1	6	5	1	4	5	2
t3s1	.	.	.	.	.	.	1	4	5	1
t3s2	3	2	999	2	6	4	1	4	5	2
t3s2	3	2	999	2	1	5	1	4	5	2
t3s2	.	.	.	.	.	.	1	4	5	1
t3s3	3	2	7	2	2	8	1	4	5	4
t3s3	3	2	7	2	1	8	1	4	5	5
t3s3	.	.	.	.	.	.	1	4	5	1
t3s4	3	2	10	2	5	8	2	4	13	6
t3s4	1	2	10	2	5	7	2	4	13	3
t3s4	.	.	.	.	.	.	2	4	13	1
t3s5	2	3	999	1	1	8	1	4	6	6
t3s5	2	3	999	2	0	2	1	4	6	1
t3s5	.	.	.	.	.	.	1	3	6	1
t4s1	2	2	999	2	1	7	2	2	7	5
t4s1	2	2	999	2	1	7	2	3	7	4
t4s1	.	.	.	.	.	.	2	2	7	1
t4s2	0	1	999	2	1	8	2	3	7	6
t4s2	2	1	999	2	1	8	2	3	7	4
t4s2	.	.	.	.	.	.	2	3	7	1
t4s3	3	2	999	2	1	7	1	3	5	4
t4s3	3	2	999	2	1	6	1	3	5	4
t4s3	.	.	.	.	.	.	1	3	5	1
t4s4	2	2	999	2	1	7	1	4	5	6
t4s4	2	2	999	2	1	7	1	4	5	5
t4s4	.	.	.	.	.	.	1	4	5	1
t4s5	2	2	999	2	6	4	1	4	5	2
t4s5	2	2	999	2	6	5	1	4	5	2
t4s5	.	.	.	.	.	.	1	4	5	1
t5s1	2	2	999	2	2	7	1	4	6	4
t5s1	2	2	999	2	2	7	1	4	6	4
t5s1	.	.	.	.	.	.	1	4	6	1
t5s2	3	1	999	2	1	7	1	2	8	4
t5s2	3	1	999	2	1	7	1	2	8	2
t5s2	.	.	.	.	.	.	1	2	8	1
t5s3	2	2	999	1	1	4	1	2	8	2
t5s3	2	2	999	2	1	6	1	4	8	4
t5s3	.	.	.	.	.	.	1	3	8	1
t5s4	3	2	999	2	6	8	.	1	9	2

Compaction data, 1987

site	COMBIN SIZE	AWARE	YLD EFF	MANURE	PLOW	PASSES	DEPO	DRAIN	SOIL TY	CR
t5s4	3	2	999	2	6	7	.	1	9	4
t5s4	.	.	.	.	.	.	.	1	9	1
t5s5	3	2	25	2	1	8	.	1	9	2
t5s5	3	2	25	2	1	7	.	1	9	2
t5s5	.	.	.	.	.	.	.	1	9	1

Compaction data, 1987

site	MOIST A	MOIST AB	MOIST B	HP A	HP AB	HP B	PIH	CP A	CP AB	CP B
d1	5	3	3	2	3.7	2.5	2.9	8.3	23.9	29.8
d1	3	3	4	1.6	1.7	1.9	-0.1	8.2	16.4	25.4
d2	3	4	4	1.2	2.1	3.7	-0.7	3.5	18.5	24.1
d2	2	3	3	2.2	2.7	3.6	-0.4	7.1	20.2	31.7
d3	2	3	3	0.5	3.2	3.3	2.6	7.4	24.6	29.8
d3	2	3	3	2.5	2.3	3.9	-1.8	9.8	19.6	27.8
d4	2	3	2	1.5	4.1	4.2	2.5	3.8	26.4	35
d4	2	3	3	2.5	3.6	3.2	1.5	9.1	21.8	26.7
d5	3	3	4	0.9	3.3	2.7	3	8.2	20.9	21.8
d5	3	3	3	1.9	2.8	3.2	0.5	8.2	21	40.6
d6	2	3	4	2.1	2.7	3.2	0.1	4.1	20	23.4
d6	3	3	3	1.9	2.8	3.2	0.5	8.2	21	40.6
d7	2	2	3	1	3.9	4	2.8	2.4	19.7	25.4
d7	2	2	2	0.6	3.6	4	2.6	19.3	40.6	56
d8	2	2	2	1.5	4.2	4.2	2.7	3.8	34.4	31.5
d8	2	2	3	1.6	2.9	3.6	0.6	12.3	24.1	31.1
d9	3	3	3	1.7	3.2	3.9	0.8	3.1	22.9	30.4
d9	3	3	3	2	2.7	2.8	0.6	9.3	18.8	24.5
d10	4	4	4	1	2.4	3.1	0.7	2.5	10.8	24.9
d10	2	2	2	2.9	3.4	4.2	-0.3	12.5	27.3	48.2
d11	4	3	2	2.9	4.1	3.4	1.9	9.9	29.4	28.4
d11	3	3	3	2.8	4.1	4.2	1.2	14.9	32.7	41
d12	3	3	3	2.6	4.1	2.9	2.7	4	20.8	25.8
d12	2	2	3	1.4	2	2.6	0	10.3	20.2	31.3
d13	2	3	3	1.8	2.4	3.4	-0.4	0	15.3	22.3
d13	2	2	3	2.4	2.7	3.5	-0.5	12.3	26.5	36.6
d14	2	2	3	1.9	3.1	2.8	1.5	5.6	17.7	25.3
d14	2	2	3	1.7	2.7	3.2	0.5	11.7	20.6	29.8
d15	2	2	2	0.9	4	4.2	2.9	7.1	27.2	25.8
d15	2	2	2	2.5	3.3	4.2	-0.1	11.1	31.3	46.5
d16	3	3	3	2.5	3.9	3.6	1.7	5.2	18.2	25.4
d16	3	3	3	2.1	3.1	4.1	0	9.3	19.1	25.3
d17	3	3	3	1.3	2.5	3.9	-0.2	1.3	20.8	23.7
d17	2	2	1	1.8	2.1	4.2	-1.8	9.3	24.7	43.4
d18	4	4	4	1.9	3	3.5	0.6	8.3	15.4	22.5
d18	2	2	3	2.5	2.8	3	0.1	11.6	18.3	27.8
d19	2	2	3	2.2	3.5	3.7	1.1	5.1	24.3	27.3
d19	3	3	3	2.5	3	3.7	-0.2	12.3	21	25
d20	3	3	4	1.6	2.9	3.5	0.7	3.6	15.7	23.6
d20	2	2	2	2	2.9	4	-0.2	12.4	26.6	38.3
t1s1	3	3	3	2.4	3.7	4.4	0.6	4.2	20.3	26.6
t1s1	5	4	4	2.7	4.3	3.7	2.2	3.5	19.2	21.5
t1s1	2	2	2	3.5	4.4	4.2	1.1	7.9	21.3	36.3
t1s2	3	3	3	1.5	4	3.7	2.8	4.2	19.6	17
t1s2	.	.	.	0.4	3.3	3.1	3.1	3.5	19.2	21.5
t1s2	.	.	.	3.1	3.1	4.2	-1.1	10	26.4	41
t1s3	3	3	3	3	3.2	3.1	0.3	2	12.6	21.9
t1s3	.	.	.	1.9	4.4	999	999	1.9	10.9	26.6
t1s3	2	2	2	3.5	4.4	999	999	12	23.2	34.2
t1s4	2	2	3	2.2	2.8	3.7	-0.3	0	12.8	22
t1s4	3	3	3	0.7	3.3	3.7	2.2	7.8	25.3	28.7
t1s4	2	2	1	2	4.3	4.5	2.1	7.7	18.1	35.2
t1s5	2	2	3	2.3	2.7	4.3	-1.2	3.6	12.7	25.8
t1s5	2	3	2	2.6	3	4	-0.6	7.3	23.4	34.8
t1s5	3	3	5	1	2.3	999	999	0.6	7.6	17.6

Compaction data, 1987

site	MOIST A	MOIST AB	MOIST B	HP A	HP AB	HP B	PIH	CP A	CP AB	CP B
t2s1	3	5	.	1.5	3.4	999	999	4.3	15.4	27.7
t2s1	4	5	4	0.9	3.8	999	999	2.6	17.8	23.8
t2s1	3	4	.	1.3	2.9	999	999	7.3	19	29.6
t2s2	3	3	3	2.7	3.4	4	0.1	15	29.2	38.5
t2s2	3	3	3	1.3	2.6	3.4	0.5	4.2	17.8	24.8
t2s2	3	3	3	1.9	2.7	2.7	0.8	5.3	18	27.2
t2s3	3	3	3	2.1	2.9	3.3	0.4	5.1	17.1	24
t2s3	3	4	3	0.9	2.6	3.4	0.9	4.8	17.4	23.3
t2s3	3	3	3	3.1	2.6	2.7	-0.6	10.9	17.9	26.7
t2s4	2	3	3	1	2.4	3.1	0.7	2	11.3	18.7
t2s4	3	4	3	1.4	2.2	2.7	0.3	4.9	17.4	31.6
t2s4	3	4	3	2.1	2.4	3	-0.3	5.4	19.9	28.5
t2s5	4	4	5	1.2	2.4	2.7	0.9	5.3	16.5	24.1
t2s5	3	3	3	1.7	2.8	2.9	1	6.9	19.6	35.1
t2s5	3	4	4	1.7	2.4	2.7	0.4	6.2	18.3	31.1
t3s1	3	3	2	2.4	2.5	4	-1.4	9	20.8	26.5
t3s1	5	5	2	0.8	2.2	2.8	0.8	0.3	16.2	17.6
t3s1	2	2	2	1.6	2.9	2.9	1.3	2	12	37
t3s2	3	3	3	0.3	0.3	3.4	-3.1	0	22.7	21.3
t3s2	3	3	3	0.5	0.5	2.6	-2.1	2.8	16.6	32
t3s2	2	2	3	1.5	1.5	2.4	-0.9	2.8	16.6	32
t3s3	5	3	3	1.4	3	3	1.6	4	12.5	16.3
t3s3	5	3	2	1.7	3.1	3	1.5	7.3	17.3	18.2
t3s3	3	3	2	2.4	2.4	4.4	-2	10.3	28.4	46.4
t3s4	5	3	3	1.3	2.3	2.5	0.8	6.8	20.8	35.3
t3s4	4	3	3	1.2	1.2	2.9	-1.7	3.8	17	33.8
t3s4	3	3	3	1.8	1.8	2.7	-0.9	2.8	14.3	21
t3s5	4	3	3	2.4	3.3	2.5	1.7	3.2	16.3	22.9
t3s5	2	3	3	2.1	2.6	2.6	0.5	5.8	15.9	25
t3s5	3	3	3	1.4	3.1	3.1	1.7	5.6	19.5	33.6
t4s1	2	2	2	0.8	4.1	2.2	5.2	2.1	17	24
t4s1	5	3	2	1.1	2.8	3.2	1.3	8.9	20.5	43
t4s1	3	3	2	2.1	2.5	2.8	0.1	6.2	15.6	26.4
t4s2	3	3	3	1.9	2.3	3.3	-0.6	3.8	16.6	20.1
t4s2	3	3	3	1.8	3.2	3	1.6	8.2	19.1	30.8
t4s2	3	3	3	2.3	2.7	2.7	0.4	12.2	22.2	26.5
t4s3	2	3	3	2.3	3	3.1	0.6	7.2	17.6	25.7
t4s3	4	3	2	2	3.7	2.8	2.6	10.5	25	32.2
t4s3	3	3	4	4.3	4	2.44	1.26	12.8	27.6	24.4
t4s4	4	5	2	1.5	3.7	3.7	2.2	3.3	19.1	28.5
t4s4	4	5	2	1.3	3.5	3.1	2.6	1.7	21.6	18.8
t4s4	4	4	4	1.5	2.3	3.3	-0.2	9.4	19.3	27.9
t4s5	4	3	4	1.8	2.9	2.4	1.6	6	17.4	23.2
t4s5	4	4	3	1.8	2.6	1.6	1.8	7.1	17.3	20.8
t4s5	3	3	3	2.6	2.6	3.2	-0.6	12.6	23.2	33.1
t5s1	5	4	3	1.5	2.9	3	1.3	3.6	19.9	22.4
t5s1	4	3	3	1.7	3.1	2.7	1.8	9.4	20.6	23.5
t5s1	2	3	3	1.8	2.5	3.7	-0.5	11.4	22.7	32.6
t5s2	4	3	4	2.8	3.3	2	1.8	2.7	17.2	17.9
t5s2	3	3	3	2.4	2.9	3.2	0.2	4.8	18.2	24.1
t5s2	2	2	2	2.8	2.7	2.4	0.2	18.3	26.8	25.5
t5s3	2	2	2	2.5	3.8	4.1	1	9.9	24.2	31.4
t5s3	2	3	3	1.5	2.8	2.7	1.4	1.3	20.9	21.2
t5s3	3	3	3	2	2.4	3	-0.2	11.5	20.6	26.4
t5s4	2	2	2	1.6	3.3	3.9	1.1	14.5	22.3	27.6

Compaction data, 1987

site	MOIST A	MOIST AB	MOIST B	HP A	HP AB	HP B	PIH	CP A	CP AB	CP B
t5s4	2	2	2	1.1	4.1	3	4.1	4.9	19.6	21.8
t5s4	2	2	2	2.4	2.4	3.3	-0.9	10.2	16.4	21.3
t5s5	2	2	2	1.7	3.5	2.9	2.4	3.3	21.2	21.9
t5s5	2	2	2	1.6	2.8	3.6	0.4	6.8	17.2	24.2
t5s5	2	2	2	2	2.4	3.1	-0.3	11.4	20	30.8

Compaction data, 1987

site	PIC	AV DROP	PEDS A	PEDS AB	PEDS B	STRUC A	STRUC AB	STRUC B	WORM	BD A
d1	9.7	4.2	1	2	1	7	5	5	2	1.36
d1	-0.8	0	2	2	2	7	7	6	999	1.11
d2	9.4	2.1	2	2	1	7	7	6	4	1.24
d2	1.6	0.8	2	2	2	7	7	7	4	1.18
d3	12	6	2	2	2	7	6	6	1	1.26
d3	1.6	0.7	2	2	2	7	7	6	999	1.09
d4	14	2	2	1	2	7	5	5	1	1.1
d4	7.8	1.8	2	2	2	7	7	6	999	1.27
d5	11.8	3.3	2	1	2	7	6	5	1	1.13
d5	-6.8	0.5	2	2	2	7	7	6	4	1.36
d6	12.5	2.8	2	1	2	7	5	5	3	1.07
d6	-6.8	0.5	2	2	2	7	7	6	4	1.36
d7	11.6	2.5	2	2	2	7	6	6	2	0.93
d7	5.9	0	2	2	2	7	7	7	2	0.8
d8	33.5	5.5	2	1	1	7	1	5	1	1.27
d8	4.8	0	2	2	2	7	7	7	4	1
d9	12.3	6	2	1	2	7	6	6	3	1.08
d9	3.8	0.8	2	2	1	7	6	6	3	0.91
d10	-5.8	0.2	2	2	2	7	6	6	999	1.13
d10	-6.1	0	2	2	2	7	7	5	999	1.02
d11	20.5	7.2	2	2	2	7	6	6	4	1.25
d11	9.5	1.8	2	2	2	7	6	6	3	1.31
d12	11.8	2.3	2	2	2	7	5	6	0	1.24
d12	-1.2	0	2	2	2	7	7	6	2	1.12
d13	8.3	0	2	2	2	7	6	6	4	1.12
d13	4.1	0	2	2	2	7	7	6	3	1.02
d14	4.5	2.5	2	2	2	6	6	6	2	1.23
d14	-0.3	0.3	2	2	2	7	7	6	4	0.93
d15	21.5	4.8	2	2	2	7	6	6	3	1.01
d15	5	0	2	2	2	7	7	6	999	1.34
d16	5.8	1	2	1	2	6	6	6	1	1.2
d16	3.6	0	2	2	2	7	7	6	3	1.31
d17	16.6	3.2	2	2	2	6	5	6	2	0.88
d17	-3.3	0	2	2	2	7	7	7	999	0.76
d18	0	1	1	2	2	6	6	5	0	1.28
d18	-2.8	0	2	2	1	7	7	6	0	1.08
d19	16.2	2.7	2	2	1	6	5	5	1	1.27
d19	4.7	0.8	2	2	2	7	7	6	999	1.37
d20	4.2	0.7	2	2	1	7	7	6	3	1.21
d20	2.5	0	2	2	2	7	7	6	4	0.97
t1s1	9.8	0	2	2	2	6	5	6	999	.
t1s1	6	6	2	1	2	6	6	6	999	.
t1s1	-1.6	0	2	2	2	7	7	7	999	.
t1s2	18	5.3	2	1	2	7	5	6	999	.
t1s2	13.4	0	2	2	1	7	7	6	999	.
t1s2	1.8	0	2	2	2	7	7	7	999	.
t1s3	1.3	1.2	2	1	2	7	7	7	999	.
t1s3	-6.7	0	2	2	999	7	6	999	4	.
t1s3	0.2	0	2	2	999	7	7	999	4	.
t1s4	3.6	0	1	2	2	7	6	6	999	.
t1s4	14.1	2.8	2	2	2	7	7	6	4	.
t1s4	-6.7	0	2	2	2	7	7	6	999	.
t1s5	-4	1.8	1	1	2	7	6	6	999	.
t1s5	4.7	2.3	2	2	2	7	6	6	999	.
t1s5	-3	1.1	2	2	2	7	7	6	2	.

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site	PIC	AV DROP	PEDS A	PEDS AB	PEDS B	STRUC A	STRUC AB	STRUC B	WORM	BD A
t2s1	-1.2	2.5	2	2	999	7	6	999	999	.
t2s1	9.2	1.8	2	1	999	7	6	999	999	.
t2s1	1.1	0	2	2	999	7	7	999	999	.
t2s2	4.9	3.8	2	2	2	7	7	7	4	.
t2s2	6.6	2.7	2	2	1	7	6	6	3	.
t2s2	3.5	0	2	2	2	6	7	7	999	.
t2s3	5.1	2.5	1	1	2	7	6	6	999	.
t2s3	6.7	1.8	2	1	2	7	6	6	2	.
t2s3	-1.8	0	2	2	2	7	6	7	999	.
t2s4	1.9	0.3	2	2	2	7	6	6	1	.
t2s4	-1.7	0.3	2	2	2	7	6	6	4	.
t2s4	5.9	0.8	2	2	2	7	7	7	4	.
t2s5	3.6	1	1	1	2	7	4	5	1	.
t2s5	-2.8	1.3	2	2	2	7	6	5	999	.
t2s5	-0.7	0	2	2	2	7	7	6	1	.
t3s1	6.1	3.3	2	2	2	7	6	6	4	.
t3s1	14.5	0.6	1	2	2	7	6	999	999	.
t3s1	-15	0	2	2	2	7	7	7	999	.
t3s2	24.1	4.2	2	2	1	7	7	6	999	.
t3s2	-1.6	0.6	2	2	2	7	7	6	999	.
t3s2	-1.6	0.8	2	2	2	7	7	6	3	.
t3s3	4.7	1.2	2	2	1	7	6	6	999	.
t3s3	9.1	3.5	1	2	2	7	6	6	999	.
t3s3	0.1	0	2	2	2	7	7	6	999	.
t3s4	-0.5	0.5	2	1	2	7	4	6	999	.
t3s4	-3.6	1.2	2	2	2	7	7	6	999	.
t3s4	4.8	0	2	2	2	7	7	6	999	.
t3s5	6.5	4.7	1	1	1	7	4	6	999	.
t3s5	1	2.2	2	2	2	7	7	7	999	.
t3s5	-0.2	0	2	2	2	7	7	6	999	.
t4s1	7.9	0.7	2	1	2	7	4	6	999	.
t4s1	-10.9	0.7	2	2	2	7	6	6	999	.
t4s1	-1.4	0	2	2	2	7	6	6	999	.
t4s2	9.3	1.7	2	1	2	7	4	6	999	.
t4s2	-0.8	1.2	1	1	2	7	4	6	999	.
t4s2	5.7	0.3	2	2	2	7	7	6	4	.
t4s3	2.3	0.7	2	2	2	7	6	6	4	.
t4s3	7.3	1.8	1	1	1	1	1	6	999	.
t4s3	18	4.5	2	2	2	6	6	6	999	.
t4s4	6.4	0.7	1	1	1	7	5	5	1	.
t4s4	22.7	6	1	1	2	7	5	5	1	.
t4s4	1.3	0.1	2	2	2	7	7	6	2	.
t4s5	5.6	0.5	2	1	2	6	5	5	999	.
t4s5	6.7	0.8	2	1	2	6	6	6	999	.
t4s5	0.7	1.3	2	2	2	7	7	6	999	.
t5s1	13.8	3	1	2	1	7	5	6	999	.
t5s1	8.3	1.8	1	1	1	7	6	6	999	.
t5s1	1.4	0.2	2	2	2	7	6	6	999	.
t5s2	13.8	4	2	1	2	7	5	6	1	.
t5s2	7.5	2	2	2	2	7	6	6	999	.
t5s2	9.8	4.3	2	2	2	7	7	7	4	.
t5s3	7.1	1.6	2	2	2	7	6	6	999	.
t5s3	19.3	3	2	1	2	7	6	6	999	.
t5s3	3.3	0	2	2	2	7	7	7	999	.
t5s4	2.5	2.5	2	2	2	7	6	7	999	.

Compaction data, 1987

site	PIC	AV DROP	PEDS A	PEDS AB	PEDS B	STRUC A	STRUC AB	STRUC B	WORM	BD A
t5s4	12.5	3.2	2	2	2	7	6	7	999	.
t5s4	1.3	1	2	2	2	7	7	7	999	.
t5s5	17.2	2.7	2	1	2	7	6	7	999	.
t5s5	3.4	1.5	2	2	2	7	6	6	2	.
t5s5	-2.2	0	2	2	2	7	7	7	999	.

Compaction data, 1987

site	BD AB	BD B	MLAB A	MLAB AB	MLAB B
d1	1.49	1.43	29.3	24.9	31.5
d1	1.21	1.39	36.8	34.7	26.0
d2	1.27	1.45	34.9	34.5	26.6
d2	1.24	1.46	30.4	29.0	23.7
d3	1.51	1.55	25.1	21.3	21.3
d3	1.23	1.56	30.0	27.2	20.6
d4	1.47	1.58	26.6	24.3	18.2
d4	1.35	1.35	26.6	26.6	27.0
d5	1.49	1.44	25.5	23.2	23.9
d5	1.34	1.49	16.3	22.2	20.2
d6	1.23	1.31	31.9	32.3	28.3
d6	1.34	1.49	16.3	22.2	20.2
d7	1.17	1.35	30.6	32.4	24.6
d7	1.09	1.37	36.1	27.0	15.6
d8	1.46	1.68	27.3	23.0	16.1
d8	1.2	1.48	40.0	31.1	19.4
d9	1.46	1.49	26.5	24.2	20.7
d9	1.36	1.3	40.2	26.3	34.6
d10	1.23	1.23	32.9	30.8	31.7
d10	1.07	1.2	32.9	30.8	28.5
d11	1.41	1.25	26.5	24.4	29.6
d11	1.42	1.41	25.5	24.5	23.8
d12	1.48	1.53	25.7	24.7	22.7
d12	1.04	1.35	26.9	31.3	16.1
d13	1.39	1.48	29.9	26.8	22.5
d13	1.1	1.44	35.8	31.5	22.2
d14	1.38	1.33	30.1	27.9	24.2
d14	1.07	1.34	31.3	28.0	23.9
d15	1.31	1.44	24.5	27.9	20.1
d15	1.37	1.45	23.3	22.7	21.1
d16	1.34	1.32	27.4	26.9	28.9
d16	1.32	1.34	27.1	25.9	24.8
d17	1.2	1.46	33.8	33.9	22.9
d17	0.82	1.23	37.0	35.3	18.1
d18	1.33	1.35	31.8	30.9	27.5
d18	1.26	1.34	27.3	23.9	25.4
d19	1.45	1.43	23.8	23.4	23.6
d19	1.37	1.58	21.1	19.8	18.4
d20	1.4	1.48	28.4	23.7	20.3
d20	1.25	1.29	31.1	23.8	26.6
t1s1	.	.	.	.	.
t1s1	.	.	.	.	.
t1s1	.	.	.	.	.
t1s2	.	.	.	.	.
t1s2	.	.	.	.	.
t1s2	.	.	.	.	.
t1s3	.	.	.	.	.
t1s3	.	.	.	.	.
t1s3	.	.	.	.	.
t1s4	.	.	.	.	.
t1s4	.	.	.	.	.
t1s4	.	.	.	.	.
t1s5	.	.	.	.	.
t1s5	.	.	.	.	.
t1s5	.	.	.	.	.

APPENDIX 4

LABORATORY ANALYSIS DATA

Analytical Services
Department of Land Resource Science
University of Guelph
Guelph, Ontario, N1G 2W1

Can-Ag Enterprises LTD.
113 Eramosa Road
Guelph, Ontario
N1E 2L9
ATTN: Leonard Leskiw
S.W.E.E.P. Soil Compaction Study

Sample Location*	pH	O. M. (Percent)	P (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)	Total P (Percent)
D1 F Sa A	7.5	3.9	25	169	760	4424	0.09
D1 F Sa B	7.5	3.6					
D1 C Sa A	7.4	6.5					
D1 C Sa B	7.7	1.7					
D2 F Sa A	6.9	4.5	20	188	820	4953	0.07
D2 F Sa B	6.9	4.4					
D2 C Sa A	7.5	5.7					
D2 C Sa B	7.6	5.1					
D3 F Sa A	7.6	3.0	161	192	824	5060	0.07
D3 F Sa B	7.3	2.9					
D3 C Sa A	7.3	6.1					
D3 C Sa B	7.5	4.4					
D4 F Sa A	7.4	3.4	33	307	900	5890	0.08
D4 F Sa B	7.5	2.4					
D4 C Sa A	7.4	4.0					
D4 C Sa B	7.5	3.0					
D5 F Sa A	7.5	5.1	12	130	660	5376	0.07
D5 F Sa B	7.5	4.0					
D6 F Sa A	7.5	7.0					
D6 F Sa B	7.4	3.6					
D6 C Sa A	7.4	5.5	17	172	870	5727	0.08
D6 C Sa B	7.6	2.2					
D7 F Sa A	7.0	4.3	5	140	680	3931	0.07
D7 F Sa B	7.1	3.4					
D7 C Sa A	7.3	8.1					
D7 C Sa B	7.2	4.4					
D8 F Sa A	7.6	3.5	25	154	517	4348	0.07
D8 F Sa B	7.5	3.0					
D8 C Sa A	7.2	7.6					
D8 C Sa B	7.2	3.8					
D9 F Sa A	7.7	3.1	23	143	520	5136	0.06
D9 F Sa B	7.7	1.3					
D9 C Sa A	7.3	7.3					
D9 C Sa B	7.3	1.7					
D10 F Sa A	7.6	3.2	25	237	990	5330	0.07
D10 F Sa B	7.4	3.3					
D10 C Sa A	7.4	6.0					
D10 C Sa B	7.4	4.5					

Sample	pH	O. M. (Percent)	P (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)	Total P (Percent)
D11 F Sa A	7.5	1.9	19	160	817	4250	0.06
D11 F Sa B	7.6	1.4					
D11 C Sa A	7.0	3.2					
D11 C Sa B	7.1	2.6					
D12 F Sa A	7.3	4.5	31	208	990	4975	0.07
D12 F Sa B	7.3	4.7					
D12 C Sa A	7.4	7.5					
D12 C Sa B	7.4	9.7					
D13 F Sa A	7.4	4.2	60	588	730	4191	0.11
D13 F Sa B	7.4	3.9					
D13 C Sa A	7.1	7.3					
D13 C Sa B	7.1	6.6					
D14 F Sa A	6.7	4.1	15	208	1100	4414	0.07
D14 F Sa B	7.0	3.9					
D14 C Sa A	7.1	6.6					
D14 C Sa B	7.1	4.9					
D15 F Sa A	5.6	2.8	8	96	464	2145	0.06
D15 F Sa B	5.5	2.8					
D15 C Sa A	6.9	2.5					
D15 C Sa B	6.7	1.7					
D16 F Sa A	5.9	3.9	21	218	843	3669	0.09
D16 F Sa B	6.0	3.9					
D16 C Sa A	6.5	3.4					
D16 C Sa B	6.8	3.2					
D17 F Sa A	7.3	9.1	17	153	955	5738	0.12
D17 F Sa B	7.3	9.1					
D17 C Sa A	7.3	13.7					
D17 C Sa B	7.3	12.3					
D18 F Sa A	6.1	4.3	8	215	953	3183	0.08
D18 F Sa B	6.1	3.9					
D18 C Sa A	7.2	5.1					
D18 C Sa B	7.2	3.3					
D19 F Sa A	7.5	3.6	60	219	1200	5030	0.11
D19 F Sa B	7.5	3.3					
D19 C Sa A	7.6	3.5					
D19 C Sa B	7.7	3.2					
D20 F Sa A	6.2	3.5	30	213	787	2193	0.09
D20 F Sa B	6.1	3.2					
D20 C Sa A	5.9	6.4					
D20 C Sa B	6.7	3.8					

* F= Field C= Control

A= A horizon B= Compacted layer or equivalent

SOIL LABORATORY ANALYSIS 01/19/87

SURVEYORS COPY

SITE = 87CAN AG SERIES = SURVEY = PM # 0 TOPO # SURVEYOR=

LAB #	HORIZON	DEPTH/ LAYER - cm -	TEXTURE	Gr	VCS	CS	MS	FS	VFS	SAND	SILT	CLAY	pH CaCl2	CaCO3 %	OrgMt %
				----	----	----	----	% by Wt	----	----	----	----			
1F A		0 0	SICL	0.0	0.0	0.0	0.0	0.0	0.0	5.45	63.3	31.2	0.0	0.0	0.0
1F B		0 0	SICL	0.0	0.0	0.0	0.0	0.0	0.0	5.58	64.1	30.3	0.0	0.0	0.0
2F A		0 0	SIC	0.0	0.0	0.0	0.0	0.0	0.0	8.25	50.5	41.2	0.0	0.0	0.0
2F B		0 0	SIC	0.0	0.0	0.0	0.0	0.0	0.0	6.79	49.8	43.4	0.0	0.0	0.0
3F A		0 0	SICL	0.0	0.6	1.1	2.5	8.5	5.3	18.05	49.8	32.2	0.0	0.0	0.0
3F B		0 0	SICL	0.0	0.6	1.1	2.1	9.8	5.5	19.19	48.2	32.6	0.0	0.0	0.0
4F A		0 0	SIC	0.0	0.0	0.0	0.0	0.0	0.0	7.99	50.8	41.2	0.0	0.0	0.0
4F B		0 0	SIC	0.0	0.0	0.0	0.0	0.0	0.0	6.35	52.4	41.2	0.0	0.0	0.0
5F A		0 0	CL	0.0	0.1	0.9	4.1	24.0	10.4	39.47	30.1	30.5	0.0	0.0	0.0
5F B		0 0	CL	0.0	0.1	0.5	2.6	24.9	9.9	38.06	31.0	31.0	0.0	0.0	0.0
6F A		0 0	C	0.0	0.1	0.6	1.9	10.2	6.0	18.83	39.5	41.6	0.0	0.0	0.0
6F B		0 0	SIC	0.0	0.0	0.0	0.0	0.0	0.0	9.19	42.0	48.8	0.0	0.0	0.0
7F A		0 0	SICL	0.0	0.0	0.0	0.0	0.0	0.0	4.64	66.5	28.9	0.0	0.0	0.0
7F B		0 0	SICL	0.0	0.0	0.0	0.0	0.0	0.0	2.89	61.5	35.6	0.0	0.0	0.0
8F A		0 0	SIL	0.0	0.8	1.2	2.0	6.2	7.9	18.09	55.0	26.9	0.0	0.0	0.0
8F B		0 0	SICL	0.0	0.2	1.1	2.7	5.5	7.2	16.70	52.7	30.6	0.0	0.0	0.0
9F A		0 0	L	0.0	1.0	1.7	2.1	10.2	10.0	24.89	49.8	25.3	0.0	0.0	0.0
9F B		0 0	SIC	0.0	0.9	0.7	1.9	4.5	3.5	11.56	42.4	46.0	0.0	0.0	0.0
10F A		0 0	C	0.0	0.4	1.4	2.7	11.7	1.1	17.28	39.7	43.0	0.0	0.0	0.0
10F B		0 0	SIC	0.0	0.2	0.6	4.1	10.1	1.2	16.19	40.4	43.4	0.0	0.0	0.0
11F A		0 0	SICL	0.0	0.0	0.0	0.0	0.0	0.0	3.06	58.0	38.9	0.0	0.0	0.0
11F B		0 0	SIC	0.0	0.0	0.0	0.0	0.0	0.0	2.74	55.6	41.6	0.0	0.0	0.0
12F A		0 0	CL	0.0	1.8	2.6	4.0	14.1	3.6	26.01	36.8	37.2	0.0	0.0	0.0
12F B		0 0	CL	0.0	0.6	2.0	5.7	11.1	3.5	23.02	37.6	39.3	0.0	0.0	0.0
13F A		0 0	CL	0.0	1.3	2.9	4.6	10.6	5.4	24.78	39.9	35.3	0.0	0.0	0.0
13F B		0 0	CL	0.0	1.7	2.3	5.7	9.3	5.6	24.71	38.9	36.3	0.0	0.0	0.0
14F A		0 0	SIC	0.0	1.1	1.4	3.1	6.9	4.7	17.20	42.3	40.5	0.0	0.0	0.0
14F B		0 0	SIC	0.0	1.1	1.2	3.5	6.4	4.5	16.64	41.9	41.5	0.0	0.0	0.0
15F A		0 0	SIL	0.0	0.3	0.9	1.6	3.5	5.4	11.68	65.4	22.9	0.0	0.0	0.0
15F B		0 0	SIL	0.0	0.1	0.7	1.9	3.6	5.8	12.21	65.3	22.5	0.0	0.0	0.0
16F A		0 0	SICL	0.0	0.1	0.5	1.6	10.6	5.0	17.81	45.3	36.9	0.0	0.0	0.0
16F B		0 0	SICL	0.0	0.1	0.4	1.8	9.7	4.8	16.89	45.6	37.5	0.0	0.0	0.0
17F A		0 0	CL	0.0	0.2	0.3	0.4	6.1	14.9	22.06	48.7	29.2	0.0	0.0	0.0
17F B		0 0	CL	0.0	0.0	0.3	0.6	5.9	14.4	21.27	49.6	29.1	0.0	0.0	0.0
18F A		0 0	C	0.0	1.3	2.8	4.5	4.2	2.0	14.87	36.8	48.3	0.0	0.0	0.0
18F B		0 0	C	0.0	1.0	2.3	5.3	3.6	2.1	14.39	37.5	48.1	0.0	0.0	0.0
19F A		0 0	SICL	0.0	0.1	0.3	0.4	1.4	11.1	13.38	51.1	35.5	0.0	0.0	0.0
19F B		0 0	SICL	0.0	0.0	0.2	0.4	1.1	9.8	11.57	52.7	35.7	0.0	0.0	0.0
20F A		0 0	CL	0.0	1.7	3.5	5.4	12.8	12.0	35.44	36.6	28.0	0.0	0.0	0.0
20F B		0 0	CL	0.0	1.7	3.2	5.4	11.9	12.1	34.30	37.2	28.5	0.0	0.0	0.0

APPENDIX 5

SUMMARY OF SOIL PROFILE DESCRIPTIONS

SITE (CR)	HORIZON Pedogenic	HORIZON Comp. Class.	DEPTH (cm)	TEXTURE	COLOR	STRUCTURE grade size kind	CONSISTENCE	POROSITY RATING
T1/S1 F1	Ap1	A	0-20	CLAY	10 YR 4/3	m f SAB	FIRM	VI B
(4)	Ap2	AB	20-26	CLAY	10 YR 4/3	m m PRISM. - m m AB	V. FIRM	V B
	Bm	B	26-40	CLAY	10 YR 5/3	wk c PRISM - f SAB	FIRM	VI B
F2	Ap1	A	0-15	CLAY	10 YR 4/2	wk m SAB	FIRM	VI B
(2)	Ap2	AB	15-20	CLAY	10 YR 4/2	wk c BL.	V. FIRM	VI A
	Bg	B	20-35	CLAY	10 YR 3/2 MAT. 7.5 YR 4/4 MOT.	s f SAB	FIRM	VI B
C	Ah	A	0-20	CLAY	10 YR 4/2	s c GR.	FRIABLE	VII B
(1)	Bm	B	20-40	CLAY	10 YR 5/3	m c PRISM. - s f SAB	FRIABLE - FIRM	VII B
T1/S2 F1	Ap1	A	0-20	CLAY LOAM	10 YR 3/3	f m GR.	FRIABLE	III B
(4)	Ap2	AB	20-28	CLAY LOAM	10 YR 3/3	s c BL.	FIRM	VI A
	Bm1	AB	28-35	SILTY CLAY	10 YR 4/4	m-s c BL.	V. FIRM	V A
	Bm2	B	35-50	CLAY	10 YR 4/4	m m SAB	FIRM	VI B
F2	Ap1	A	0-15	SILTY CLAY LOAM	10 YR 4/2	s m-c GR.	FRIABLE	VII B
(2)	Ap2	AB	15-20	SILTY CLAY LOAM	10 YR 4/2	c PRISM - s m SAB	FIRM	VI B
	Bm1	AB	20-30	CLAY	10 YR 5/4	m f SAB	FIRM	VI A
	Bm2	B	30-50	CLAY	10 YR 5/3	wk m SAB	FIRM	VI A
	Ckgj		70-100					
C	Ah	A	0-40	CLAY LOAM	10 YR 3/2	s c GR.	FRIABLE	VII B
(1)	Bgj	B	40-50	CLAY	10 YR 3/2 MAT. 7.5 YR 4/4 MOT.	s f SAB	FIRM	VII B
T1/S3 F1	Ap	A	0-18	SILTY CLAY	10 YR 5/2	m m BL.	FIRM	VI B
(2)	Bg1	AB	18-23	SILTY CLAY	10 YR 5/1 MAT. 7.5 YR 4/4 MOT.	m c BL. - SAB	FIRM	VI A
	Bg2	B	23-40	SILTY CLAY	10 YR 5/1 MAT. 7.5 YR 4/4 MOT.	wk. f SAB	FIRM	VI B
F2	Ap	A	0-30	SILTY CLAY	10 YR 4/2	s m-f SAB	FRIABLE	VII B
(2)	Bgj	AB	30-60	SILTY CLAY	10 YR 4/1	s f-m SAB	FRIABLE - FIRM	VI B
	Bg	B	60-80	CLAY	10 YR 5/1 MAT. 7.5 YR 4/4 MOT.	s f-m SAB	V. FIRM	VI B
C	Ah	A	0-20	SILTY CLAY	10 YR 4/2	s c GR.	FRIABLE	VII B
(1)	Bgj	B	20-50	SILTY CLAY	10 YR 5/1 MAT. 7.5 YR 4/4 MOT.	s f SAB	FRIABLE - FIRM	VII B
T1/S4 F1	Ap1	A	0-20	SILTY CLAY	10 YR 4/2	s m GR.	FRIABLE	VII A
(4)	Ah	A	20-35	SILTY CLAY	10 YR 4/2	m m SAB	FIRM	VI B
	Bgj	B	35-50	SILTY CLAY	10 YR 4/1 MAT. 7.5 YR 5/6 MOT.	m m SAB	FIRM	VI B

T1/S1: Transect 1/Site 1
F1: Field 1
F2: Field 2
C: Control
(4): Compaction Rating (1) none through (6) severe

SITE (CR)	HORIZON Pedogenic	HORIZON [illegible]	DEPTH (cm)	TEXTURE	COLOR	STRUCTURE grade size kind	CONSISTENCE	POROSITY RATING
T1/34 F2	Ap1	A	0-20	SILTY CLAY	10YR 4/2	WK m GR.	FRIABLE	VII B
(1)	Ap2	AB	20-35	SILTY CLAY	10YR 4/2	m m SAB	FIRM	VII B
	Bgj	B	35-60	SILTY CLAY	10YR 5/1 mat. 7.5YR 5/6 mot.	m f SAB	FIRM	VI B
C	Ah	A	0-25	SILTY CLAY	10YR 3/3	s f-m GR.	FRIABLE	VII B
(1)	Bm	B	25-45	SILTY CLAY	10YR 4/2	s f SAB	FRIABLE	VI B
	Cgj		45-60	CLAY LOAM	10YR 5/2	s m SAB	V. FIRM	
T1/35 F1	Ap1	A	0-20	SILTY CLAY	10YR 4/2	m f GR.	FRIABLE	VII A
(2)	Ap2	AB	20-26	SILTY CLAY	10YR 4/2	m m SAB	FIRM	VI A
	Bg	B	26-40	SILTY CLAY	10YR 6/2 mat. 7.5YR 5/6 mot.	m m SAB	FIRM	VI B
F2	Ap1	A	0-16	SILTY CLAY	10YR 4/2	M M GR.	FRIABLE	VII B
(4)	Ap2	AB	16-28	Si C	10YR 4/2	M C BL. - M M SAB	FIRM	VII B
	Bgj	B	28-40	CL	10YR 5/2 mat. 7.5YR 5/6 mot.	M f SAB	FIRM	VI B
C	Ah	A	0-25	Si CL	10YR 3/2	s M GR.	FRIABLE	VII B
(1)	Bg	B	25-55	SiC	10YR 5/2 mat. 7.5YR 5/6 mot.	s f SAB.	FRIABLE	VI B
T2/31 F1	Ahgj	A	0-20	SiC	10YR 5/2	M M GR.	FRIABLE	VII B
(2)	Bg	B	20-40	SiC	10YR 5/1 mat. 7.5YR 5/6 mot.	M f SAB	FIRM	VI B
F2	Ap	AB	0-20	SiC	10YR 4/2	m m GR.	FRIABLE	VII B
(4)	Bg	B	20-50	SiC	10YR 5/1 mat. 7.5YR 5/6 mot.	WK. f. SAB	FIRM	VI A
C	Ah	A	0-20	SILTY CLAY	10YR 5/2	s c GR.	FRIABLE	VII B
(1)	Bg	B	20-45	SILTY CLAY	10YR 5/1 mat. 7.5YR 5/6 mot.	s f SAB	FIRM	VII B
T2/32 F1	Ap	A	0-28	SILTY CLAY	10YR 4/2	s m GR.	FRIABLE	VII B
(1)	Bgj	B	28-48	SILTY CLAY	10YR 5/2	m f SAB	FIRM	VII B
	CK		48-60					
F2	Ap1	A	0-15	SILTY CLAY	10YR 4/2	m m GR.	FRIABLE	VII B
(3)	Ap2	AB	15-24	SILTY CLAY	10YR 4/2	m m-f SAB	FIRM	VI B
	Bgj	B	24-40	SILTY CLAY LOAM	10YR 5/4	WK f SAB	FIRM	VI A
C	Ah	A	0-38	SILTY CLAY	10YR 3/2	s f GR.	FRIABLE	VII B
(1)	Bgj	B	38-50	SILTY CLAY	10YR 4/2	m f SAB	FIRM	VI B

SITE (CR)	HORIZON Pedogenic	HORIZON [illegible] Class	DEPTH (cm)	TEXTURE	COLOR	STRUCTURE grade size kind	CONSISTENCE	POROSITY RATING
T2/33 F1	Ap1	A	0-15	CLAY	10YR 6/2	WK m GR.	FRIABLE - FIRM	VII A
(4)	Ap2	AB	15-28	CLAY	10YR 5/2	WK m SAB	FIRM	VI A
	Bg	B	28-45	CLAY	10YR 5/1	m f SAB	FIRM	VI B
F2	Ap1	A	0-19	CLAY	10YR 5/2	m m GR.	FRIABLE	VII B
(3)	Ap2	AB	19-30	CLAY	10YR 5/2	m c SAB	FIRM	VII A
	Bg	B	30-50	CLAY	10YR 5/1 MAT. 7.5YR 4/8 MOT.	S f SAB	V. FIRM	VI B
C	Ah	A	0-10	CLAY	10YR 5/2	m m GR.	FRIABLE	VII B
(1)	AB	A	10-30	CLAY	10YR 5/2	m f SAB	FIRM	VII B
	Buried A	A	30-45	CLAY	10YR 5/2	S c GR.	FRIABLE	VII B
	Bg	B	45-55	CLAY	10YR 6/1 MAT. 7.5YR 5/8 MOT.	S f SAB	FIRM	VI B
T2/34 F1	Ap1	A	0-18	SILTY CLAY	10YR 4/1	S m GR.	FRIABLE	VII B
(2)	AB	AB	18-28	CLAY	10YR 4/1	m f SAB	FIRM	VI B
	Bg	B	28-52	CLAY	10YR 5/1 MAT 7.5YR 5/8 MOT	m f SAB	- FIRM	VI B
F2	Ap1	A	0-15	SILTY CLAY	10YR 4/1	m f GR.	FRIABLE	VII B
(1)	AB	AB	15-30	SILTY CLAY	10YR 4/1	m f SAB	FIRM	VI B
	Bg	B	30-50	SILTY CLAY	10YR 6/1 - 4/1 MAT. 7.5YR 5/8 MOT.	m f SAB	FIRM	VI B
C	Ah	A	0-32	SILTY CLAY LOAM	10YR 4/2	S m GR.	FRIABLE	VII B
(1)	Bg	B	32-50	SILTY CLAY LOAM-C	10YR 6/1 (MAT) 7.5YR 5/8 MOT	S f SAB	FIRM	VII B
T2/35 F1	Ap1	A	0-15	CLAY	10YR 4/1	WK f-m GR.	FRIABLE	VII A
(6)	Ap2	AB	15-26	CLAY	10YR 4/1	WK c BL.	FIRM	IV A
	Bg	B	33-48	CLAY	10YR 6/1 MAT 7.5YR 5/8 MOT.	m f SAB	FIRM	V B
F2	Ap1	A	0-18	CLAY	10YR 4/1	m m GR.	FRIABLE	VII B
(4)	Ap2	AB	18-38	CLAY	10YR 4/1	m f SAB	FIRM	VI B
	Bg	B	38-55	CLAY	10YR 6/1 MAT 7.5YR 5/8 MOT	m f SAB	FIRM	V B
C	Ah	A	0-25	CLAY	10YR 5/1	S m GR.	FRIABLE	VII B
(1)	AB	A	25-40	CLAY	10YR 4/1	S f SAB	FRIABLE	VII B
	Bg	B	40-50	CLAY	10YR 6/1 MAT 7.5YR 5/8 MOT.	m f SAB	FIRM	VI B

SITE (CR)	HORIZON Pedogenic	HORIZON Comp. Class	DEPTH (cm)	TEXTURE	COLOR	STRUCTURE grade size kind	CONSISTENCE	POROSITY RATING
T3/31 F1	Ap1	A	0-23	SiCL	10YR 4/2	wk m gr.	Friable	VII B
(4)	Ap2	AB	23-27	SiCL	10YR 4/2	m m SAB	Firm	VI B
	Bg	B	27-50	SiCL	10YR 5/2 mat 7.5YR 4/6 mot	s f SAB	Firm	VI B
F2	Ap1	A	0-20	SiC	10YR 4/2	m m gr.	Friable	VII A
(2)	Ap2	AB	20-26	SiC	10YR 4/2	m m SAB	Firm	VI B
	Bg	B	26-58	SiCL	10YR 5/2 mat 7.5YR 4/6 mot	s c SAB	Firm	
C	Ah	A	0-20	SiC	10YR 3/1	s m&c gr	Friable	VII B
(1)	Bg	B	20-45	SiCL	10YR 5/2 mat 7.5YR 6/8 mot	s f SAB	Friable	VII B
T3/32 F1	Ap	A-AB	0-28	SiCL	10YR 4/2	s f SAB & s c gr.	Friable	VII B
(2)	Bg	B	28-50	SiC	10YR 5/2 mat 7.5YR 3/8 mot	m m SAB	Firm	VI A
F2	Ap	A-AB	0-30	SiCL	10YR 4/2	m c gr to m f SAB	Friable	VII B
(2)	Bg	B	30-50	SiCL	10YR 5/2 mat 7.5YR 5/8 mot	m m SAB	Firm	VI B
C	Ah	A	0-23	SiCL	10YR 3/2	s c gr	Friable	VIII B
(1)	Bg	B	23-45	SiC	10YR 5/1 mat 7.5YR 4/8 mot	m f SAB.	Friable - Firm	VI B
T3/33 F1	Apgj	A-AB	0-30	SiC	10YR 4/2	s m SAB	Friable - Firm	VII B
(4)	Bg	B	30-50	SiC	10YR 6/1 mat 7.5YR 4/8 mot	wk f SAB	Firm	VI A
F2	Ap1	A	0-16	SiC	10YR 3/1	wk m gr.	Friable	VII A
(5)	Ap2	AB	16-23	SiC	10YR 3/1	m m SAB	Firm	VI B
	Bg	B	23-45	SiC	10YR 6/1 mat 7.5YR 4/8 mot	m f SAB	Firm	VI B
C	Ah	A	0-27	SiC	10YR 4/2	s c gr	Friable	VII B
(1)	Bg	B	27-40	SiC	10YR 5/1 mat 7.5YR 4/8 mot	s m SAB	Firm	VI B
T3/34 F1	Ap1	A	0-16	C	10YR 4/2	m m gr	Friable	VII B
(6)	Ap2	AB	16-28	C	10YR 4/2	wk f SAB	Firm	IV A
	Bg	B	28-50	C	10YR 6/1 mot 7.5YR 5/8 mot	s f SAB	Firm - V. Firm	VI B
F2	Ap	AB	0-23	C	10YR 5/2	m-s f SAB	Friable - Firm	VII B
(8)	Bg	B	23-65	C	10YR 6/1 mat 7.5YR 5/8 mot	m f SAB	Firm	VI B
	CKg		65-70				V. Firm	
C	Ah	A	0-20	C	10YR 5/2	m c gr - m f SAB	Friable	VII B
(1)	Bg	B	20-40	C	10YR 5/2 mat 7.5YR 4/6 mot	s m SAB	Firm	VI B

SITE (CR)	HORIZON Pedogenic	HORIZON Coop. class	DEPTH (CM)	TEXTURE	COLOR	STRUCTURE grade size kind	CONSISTENCE	POROSITY RATING
T3 /55 F1	Ap	A	0-18	C	10YR 5/2	WK m GR.	FIRM	VII A
(6)	Bg1	AB	18-28	C	10YR 4/1 mat 7.5YR 4/6 mot	MASSIVE	V. FIRM	IV A
	Bg2	B	28-50	C	10YR 6/1 mat 7.5YR 4/6 mot	WK f SAB	FIRM	VI A
F2	Ap	A	0-25	SiC	10YR 4/2	S m GR	FRIABLE	VII B
(1)	Bg	B	25-55	SiC	10YR 5/2 mat 7.5YR 4/6 mot	m f SAB	FIRM	VII B
	CKg		55-70					
C	Ah	A	0-25	C	10YR 4/2	m m GR	FRIABLE	VII B
(1)	Bgj	B	25-45	C	10YR 5/1	m m SAB	FRIABLE - FIRM	VII B
T4 / 51 F1	Ap1	A	0-22	C	10YR 3/1	S m SAB & S m GR	FRIABLE - FIRM	VII B
(6)	Ap2	AB	22-30	C	10YR 4/1	m m BL.	V. FIRM	IV B
	Bg1	AB	30-40	SiC	10YR 6/1 mat 7.5YR 5/6 mot	m m SAB	V. FIRM	VI A
	Bg2	B	40-65	SiC	"	WK f SAB	FIRM	VI B
F2	Ap1	A	0-6	C	10YR 3/1	WK m GR.	FIRM	VII B
(4)	Ap2	AB	6-28	C	10YR 3/1	WK f SAB	V. FIRM	VI B
	Bgj	B	28-60	C	10YR 3/1	m f SAB	FIRM - V. FIRM	VI B
	CKg		60-75					
C	Ah	A	0-30	C	10YR 3/1	S m GR.	FRIABLE	VII B
(1)	Bg	B	30-50	C	10YR 5/2 mat 7.5YR 4/6 mot	m m SAB	FIRM	VI B
T4 /52 F1	Ap1	A	0-20	C	10YR 4/1	m m-f GR.	FRIABLE	VII B
(6)	Ap2	AB	20-35	C	10YR 4/1	WK m BL.	V. FIRM	IV A
	Bgj	B	35-50	C	10YR 5/1	m m SAB	FIRM	VI B
F2	Ap1	A	0-20	C	10YR 4/1	m m SAB - WK m GR	FIRM - FRIABLE	VII A
(4)	Ap2	AB	20-36	C	10YR 4/1	WK f SAB	FIRM - FRIABLE	IV A
	Bgj	B	36-50	C	10YR 6/1 mat 7.5YR 4/6 mot	m f SAB	FIRM	VI B
C	Ah	A	0-45	C	10YR 4/1	S c GR - S f SAB	FRIABLE	VII B
(1)	Bgj	B	45-60	C	10YR 5/1 mat 7.5YR 4/6 mot	m f SAB	FIRM	VI B
T4 /53 F1	Ap1	A	0-22	C	10YR 3/2	m c GR.	FRIABLE	VII B
(4)	Ap2	AB	22-45	C	10YR 3/2	m f SAB	FIRM	VI B
	Bg	B	45-58	SiC	10YR 6/1 mat 7.5YR 5/6 mot	m f SAB	FIRM	VI B
F2	Ap	AB	0-35	SiC - C	10YR 4/2	MASSIVE	V. FIRM	I A
(4)	Bg	B	35-50	SiC - C	10YR 6/1 mat 7.5YR 5/6 mot	WK f SAB	FIRM	VI A

SITE (CR)	HORIZON Pedogenic	HORIZON Comp. Class	DEPTH (cm)	TEXTURE	COLOR	STRUCTURE grade size kind	CONSISTENCE	POROSITY RATING
T4/133 C	Ah	A	0-42	C	10 YR 4/2	s c GR. & s f SAB	FRIABLE - FIRM	VI B
(1)	Bgj	B	42-50	C	10 YR 5/2	m f SAB	FIRM	VI B
T4/154 F1	Ap	A	0-21	C	10 YR 5/2	WK f GR.	FRIABLE	VII A
(6)	Bg1	AB	21-40	C	10 YR 5/2 mat 7.5 YR 5/8 mot	WK f SAB	V. FIRM	V A
	Bg2	B	40-50	C	10 YR 5/2 mat 7.5 YR 5/8 mot	m f SAB	FIRM	V B
	Ckg		65-75					
F2	Ap	A	0-26	C	10 YR 4/2	WK m-f GR.	FRIABLE	VII A
(5)	Bg1	AB	26-40	C	10 YR 6/1 mat 7.5 YR 5/6 mot	WK c BL.	V. FIRM	V A
	Bg2	B	40-62	C	10 YR 6/1 mat 7.5 YR 5/6 mot	m f SAB	FIRM	V B
C	Ah	A	0-30	C	10 YR 4/2	s m GR.	FRIABLE	VII B
(1)	Bg	B	30-50	C	10 YR 5/2 mat 7.5 YR 5/8 mot	s f SAB	FIRM	VI B
T4/155 F1	Ap	A	0-22	SiC - C	10 YR 5/2	m m-f GR.	FRIABLE	VI B
(2)	Bg	B	22-45	C	10 YR 6/1 mat 7.5 YR 5/6 mot	WK f SAB	FIRM	V A - V B
F2	Ap	A	0-24	SiC	10 YR 5/2	m m-f GR.	FRIABLE	VI B
(2)	Bg	B	24-50	SiC	10 YR 6/1 mat 7.5 YR 5/8 mot	m m SAB	FIRM	VI A - VI…
C	Ah	A	0-30	SiC	10 YR 3/2	m c GR.	FRIABLE	VII B
(1)	Bg	B	30-50	SiC	10 YR 6/1 mat 7.5 YR 5/6 mot.	m m SAB - s SAB	FRIABLE	VI B
T5/151 F1	Ap1	A	0-16	C	10 YR 4/2	WK m-f GR.	FRIABLE	VII A
(4)	Ap2	AB	16-28	C	10 YR 4/2	m f SAB	FIRM	V B
	Bg	B	28-60	C	10 YR 5/1 mat 7.5 YR 5/8 mot	WK f SAB	FIRM	V B - VI…
F2	Ap1	A	0-17	C	10 YR [illegible]	WK f GR.	FRIABLE	VII A
(4)	Ap2	AB	17-25	C	10 YR 4/2	WK c BL - m-WK f SAB	FIRM	VI A
	Bg	B	25-65	C	10 YR 5/1 mat 7.5 YR 5/8 mot.	WK f SAB	FIRM	VI A
C	Ah	A	0-22	C	10 YR 4/1	s m GR.	FRIABLE	VII B
(1)	Bg	B	22-40	C	10 YR 5/2 mat 7.5 YR 5/8 mot	s f SAB	FRIABLE - FIRM	VI B
T5/152 F1	Ap	A	0-18	SiCL	10 YR 4/4	m f SAB	FRIABLE	VI B
(4)	Bt	AB	18-30	SiC	10 YR 4/4	V. WK f SAB	V. FIRM	V A
	Ck1		30-40	SiC	10 YR 4/2	m f SAB	FIRM	VI B
	Ck2		40-50	SL	10 YR 4/3	WK f SAB	LOOSE	

SITE (CR)	HORIZON		DEPTH (cm)	TEXTURE	COLOR	STRUCTURE grade size Kind	CONSISTENCE	POROSITY RATING
	[illegible]	[illegible]						
T3 / 52 F2	Ap	A	0 - 18	SiCL	10YR 4/2	m m-f GR.	FRIABLE.	VIIB
(2)	Bt	B	18 - 35	. C	10YR 5/1	m f SAB	FIRM	VIIB
	Ck		35 - 50	C	10YR 5/2	m f SAB	FIRM	VIIB
C	Ah	A	0 - 22	SiCL	10YR 4/2	s f-m GR.	FRIABLE	VIIB
(1)	Btj	B	22 - 45	SiCL	10YR 4/3	s f SAB	FIRM	VIIB
	Ck		45 - 60	SiC				
T3 / 53 F1	Ap1	A	0 - 18	CL - C	10YR 4/3	m f GR - m s SAB	FRIABLE	VIIB
(2)	Ap2	AB	18 - 33	CL - C	10YR 4/3	c BL - m f SAB	FIRM	VIB
	Bt	B	33 - 50	C	10YR 3/3	m f SAB	FIRM	VIB
F2	Ap1	A	0 - 18	CL - C	10YR 4/2	m f GR.	FRIABLE	VIIB
(4)	Ap2	AB	18 - 30	CL - C	10YR 4/2	wk f SAB	V. FIRM	VIA
	Bg	B	30 - 45	CL	10YR 5/1 mat. 7.5YR 5/8 mot.	m f SAB	FIRM	VIB
C	Ah	A	0 - 18	L - CL	10YR 4/2	s m-f GR	FRIABLE	VIIB
(1)	Bg	B	18 - 45	L - CL	10YR 5/2 mat. 7.5YR 5/8 mot.	m f SAB	FIRM	VII A - B
T3 / 54 F1	Ap	A	0 - 32	SiCL	10YR 4/2	m m-f GR.	FRIABLE	VIIB - VIB
(2)	Bm	B	32 - 50	SiC	10YR 4/4	s m SAB	FIRM	VIIB
F2	Ap1	A	0 - 18	CL	10YR 4/2	m f GR.	FRIABLE	VIIB
(4)	Ap2	AB	18 - 34	CL	10YR 4/2	m m SAB	FIRM	VIB
	Bm	B	34 - 48	CL	10YR 5/4	m-s f SAB	FRIABLE	VIIB
C	Ah	A	0 - 28	CL	10YR 4/2	s m-f GR.	FRIABLE	VIIB
(1)	Bm	B	28 - 42	CL	10YR 5/3	s f SAB	FRIABLE	VIIB
T3 / 55 F1	Ap	A	0 - 28	L - CL	10YR 5/3	m m-f GR	FRIABLE	VIIB - VIA
(2)	Bm	B	28 - 50	L - CL	10YR 6/4	m f SAB	FRIABLE	VIIB
F2	Ap	A	0 - 28	L - CL	10YR 5/3	m m-f GR.	FIRM	VIIB - VIB
(2)	Bm	B	28 - 45	CL - C	10YR 4/4	m f SAB	FIRM	VIB
C	Ah	A	0 - 30	L - CL	10YR 4/2	s m GR	FRIABLE	VIIB
(1)	Bm	B	30 - 40	L - CL	10YR 4/4	m f SAB	FRIABLE	VIIB

SITE (CR)	HORIZON Pedogenic	HORIZON Simp. Class	DEPTH (cm)	TEXTURE	COLOR	STRUCTURE grade size kind	CONSISTENCE	POROSITY RATING
D1 F	Ap1	A	0-18	C-SiC	10YR 3/2	m-wk f GR	Friable	VIIA
(4)	Ap2	AB	18-28	C-SiC	10YR 3/3	c BL - f BL & f SAB	Firm - V. Firm	VB
	Bm	B	28-42	C-SiC	10YR 3/4	wk f SAB	Firm - V. Firm	VB
	CKgj		42-55					
C	Ah	A	0-25	SiC-C	10YR 3/2	s m GR.	Friable	VIIB
(1)	Bm	B	25-45	SiC-C	10YR 5/4	m f SAB	Friable	VIIB - V
D2 F	Ap1	A	0-18	C-SiC	10YR 4/3	m m-f GR	Friable	VIIB
(2).	Ap2	AB	18-27	C-SiC	10YR 3/2	m m SAB - m f SAB	Firm	VIIB
	Bg	B	27-40	C-SiC	10YR 5/2 mat 7.5YR 5/8 mot	v. wk f SAB	V. Firm	VIA - VIB
C	Ah	A	0-25	C-SiC	10YR 3/2	s f GR	Friable	VIIB
(1)	Bg	B	25-40	C-SiC	10YR 5/2 mat 7.5YR 5/8 mot	s f SAB	Friable	VIIB
D3 F	Ap1	A	0-17	C-CL	10YR 3/3	m m-f GR	Friable	VIIB
(4)	Ap2	AB	17-26	C-CL	10YR 3/3	m m BL - m f SAB	Firm	VIB
	Bg	B	26-50	C-SiC	10YR 5/1 mat 7.5YR 5/6 mot	wk f SAB	Firm - V. Firm	VA - VI
C	Ah	A	0-25	C-CL	10YR 4/3	s m GR	Friable	VIIB
(1)	Bg	B	25-50	C-CL	10YR 5/2 mat 7.5YR 5/6 mot	s f SAB	Friable - Firm	VIB
D4 F	Ap1	A	0-30	C	10YR 4/3	m m-f GR - s f SAB	Friable - Firm	VIIB
(6)	Ap2	AB	30-36	C	10YR 4/3	m-s m BL - m f SAB	V. Firm	VB
	Bgj	B	36-45	C	10YR 5/2	wk f SAB	V. Firm	VA
	CKgj		45-60	C	10YR 5/2	m f SAB	V. Firm	VB
C	Ah	A	0-32	C-CL	10YR 4/3	s m GR	Friable	VIIB
(1)	Bgj	B	32-55	C-SiC	10YR 5/1	m m-f SAB	Firm	VIIB - VIB
D5 F	Ap1	A	0-22	CL	10YR 3/2	wk c GR - s c GR	Friable	VIIB
(4)	Ap2	AB	22-36	CL	10YR 3/2	wk f SAB	Firm	VIA
	Bg	B	36-45	CL	10YR 5/1 mat 7.5YR 5/8 mot	wk f SAB	Firm	VI A
	CKg		45-55	CL	10YR 5/1 mat 7.5YR 5/8 mot	m f SAB	Firm	VB
D5 & D6 C	Ah	A	0-19	CL	10YR 4/2	s m-f GR	Friable	VIIB
(1)	Bg	B	19-34	CL	10YR 5/2 mat 7.5YR 5/6 mot	m f SAB	Firm - Friable	VIB
	CKg		34-50	CL	10YR 5/2 mat 7.5YR 5/6 mot	m f SAB	Firm	
D6 F	Ap1	A	0-18	CL	10YR 4/2	s f GR	Friable	VIIB
(3)	Ap2	AB	18-25	CL	10YR 4/2	m m BL - m f SAB	Firm	VIB
	Bg	B	25-55	C-CL	10YR 4/1-5/1 mat 7.5YR 5/8 mot	m f SAB	V. Firm	VA - VB

D1: Detailed 1
F: Field
C: Control
(4): Compaction Rating (1) none through (6) severe

SITE (CR)	HORIZON		DEPTH (CM)	TEXTURE	COLOR	STRUCTURE grade size kind	CONSISTENCE	POROSITY RATING
D7 F	Ap	A	0-27	C-SIC	10 YR 4/3	m m-f GR	FRIABLE	VIIB
(2)	Bgj	B	27-55	C-SIC	10 YR 5/3	m f SAB	FRIABLE - FIRM	VIB
C	Ah	A	0-20	CL	10 YR 4/2	s m-f GR	FRIABLE	VIIB
(1)	Bm	B	20-30	CL	10 YR 5/2	s f SAB	FRIABLE	VIIB
	Bmgj	B	30-50	CL	10 YR 6/2 MAT 10 YR 5/6 MOT.	s f SAB	FRIABLE	VII B
D8 F	Ap1	A	0-17	C-CL	10 YR 3/2	m m GR & f SAB	FRIABLE - FIRM	VIIB
(6)	Ap2	AB	17-21	C-CL	10 YR 3/2	WK m SAB	FIRM	VA
	Bg1	AB	21-33	C-CL	10 YR 3/2	MASSIVE	V. FIRM	IA
	Bg2	B	33-40	C-CL	10 YR 6/1 & 5/3 MAT 7.5 YR 5/8 MOT	WK f SAB	FIRM	VA
	CKg		40-60	C-CL	"	WK m SAB	FIRM	
C	Ah	A	0-18	C-CL	10 YR 4/2	s-f C GR.	FRIABLE	VIIB
(1)	Bg	B	18-50	C-CL	10 YR 6/2 MAT 7.5 YR 5/8 MOT	s m SAB - f SAB	FRIABLE - FIRM	VIIB
	CKg		50-60					
D9 F	Ap	A	0-30	C-CL	10 YR 4/2	m m SAB - m m-f GR.	FRIABLE	VII B
(3)	Bgj	AB	30-40	C-CL	10 YR 6/2	WK f SAB	FIRM	VIA - VIIB
	CKgj		40-50	C-CL	10 YR 6/1	m f SAB	FIRM	VIB
C	Ah	A	0-20	C-CL	10 YR 3/2	m m-f GR.	FRIABLE	VIIB
(1)	Bg	B	20-50	C-CL	10 YR 6/2 MAT 10 YR 4/6 MOT.	m-WK f SAB	FIRM	VIA - VIB
D10 F	Ap1	A	0-25	C	10 YR 5/2	m m-f GR	FRIABLE	VII B
(1)	Ap2	AB	25-35	C	10 YR 5/2	m f SAB	FIRM	VIB
	Bg	B	35-50	C	10 YR 6/1 - 5/2 MAT 7.5 YR 5/8 MOT	m m SAB	FIRM	VIB
C	Ah	A	0-20	C	10 YR 4/2	m-s m GR - f SAB	FRIABLE	VIIB
(1)	Bg	B	20-30	C	10 YR 3/1 MAT 7.5 YR 5/6 MOT	m f SAB	FIRM	VIIB
D11 F	Ap	A	0-30	CL	10 YR 4/2	m f SAB	FRIABLE	VII B
(3)	AB	A	30-45	C	10 YR 4/2	m m BL - m f SAB	FIRM	VIB
	Bgj	AB	45-50	C-SIC	10 YR 5/8	m m SAB - f SAB	FIRM	VIB
C	Ah	A	0-25	C-CL	10 YR 4/2	m m GR - s f SAB	FRIABLE - FIRM	VII B
(1)	AB	A	25-35	C-CL	10 YR 3/2	m f SAB	FIRM	VIB
	Bgj	B	35-45	C-CL	10 YR 5/6	m f SAB	FIRM	VIB

SITE (CR)	HORIZON		DEPTH (cm)	TEXTURE	COLOR	STRUCTURE grade size kind	CONSISTENCE	POROSITY RATING
	[illegible]	COMP. CODE						
D12 E	Ap1	A	0-19	C-CL	10YR 3/1	m m-f GR.	FRIABLE	VII B
(6)	Ap2	AB	19-30	C-CL	10YR 5/1	m m BL - m f SAB	V. FIRM	V B
	Bg	B	30-50	HC	10YR 5/1 mat 7.5YR 4/6 mot	m f SAB	V. FIRM	VI B
C	Ah	A	0-42	CL	10YR 3/1	m m GR - s m-f SAB	FIRM	VII B
(1)	Bg	B	42-55	C	10YR 5/1 mat 7.5YR 5/8 mot	m m SAB	FIRM	VI B
D13 E	Ap1	A	0-24	C	10YR 4/3	m m-f GR & f SAB	FRIABLE	VII B
(8)	Ap2	AB	24-33	C	10YR 4/3	m f SAB	FIRM	VI B
	Bg	B	33-50	C	10YR 6/1 mat 7.5YR 5/8 mot	m f SAB	FIRM	VI B
C	Ah	A	0-36	C	10YR 4/1	s m-f GR.	FRIABLE	VII B
(1)	Bg	B	36-50	C	10YR 5/2 mat 7.5YR 5/6 mot	m f SAB	FRIABLE - FIRM	VI B
D14 F	Ap1	A	0-20	CL	10YR 4/2	m f SAB	FRIABLE	VI B
(3)	Ap2	AB	20-35	CL	10YR 4/2	wk m BL - m f SAB	FIRM	VI B
	Bg	B	35-55	C-CL	10YR 6/2 mat 10YR 5/6 mot	m f SAB	FIRM	VI B
C	Ah	A	0-30	C-CL	10YR 4/2	s m-c GR.	FRIABLE	VII B
(1)	Bg	B	30-45	C-CL	10YR 6/2 mat 10YR 5/6 mot	m-s f SAB	FRIABLE - FIRM	VII B - VI
D15 E	Ap1	A	0-20	CL	10YR 5/3	m m-f GR & m f SAB	FIRM	VII B
(8)	Ap2	AB	20-34	CL	10YR 5/3	wk m BL - m f SAB	FIRM	VI B
	Btj	B	34-50	SiCL	10YR 6/4	m-s f SAB	FIRM	VI B
C	Ah	A	0-27	CL	10YR 4/3	m-s m-f GR	FRIABLE	VII B
(1)	Btj	B	27-45	CL	10YR 5/6	m-s f SAB	FRIABLE - FIRM	VI B
D16 E	Ap1	A	0-20	C-CL	10YR 3/2	m m-f SAB	FIRM - FRIABLE	VI B
(3)	Ap2	AB	20-30	C-CL	10YR 5/2	wk-m m-f SAB	FIRM	VI A
	Bg	B	30-50	C-SiC	10YR 6/1 mat 7.5YR 5/8 mot	m f SAB	FIRM	VI B
C	Ah	A	0-30	C-CL	10YR 3/2	m f SAB	FRIABLE	VII B
(1)	Bg	B	30-50	C-CL	10YR 6/1 mat 7.5YR 5/8 mot	m-s f SAB	FIRM	VI A
D17 F	Ap1	A	0-20	C-SiC	10YR 3/1	s m-f SAB	FIRM	VI B
(4)	Ap2	AB	20-33	C-SiC	10YR 3/1	WK. BL.	FRIABLE - FIRM	V B
	Bg	B	33-55	C-SiC	10YR 5/1 mat 7.5YR 5/6 mot	m f SAB	FIRM	VI B
C	Ah	A	0-34	C-SiC	10YR 3/2	s m-f GR.	LOOSE	VII B
(1)	Bg	B	34-60	C-SiC	10YR 5/1 mat 7.5YR 5/6 mot	s m-f SAB	FRIABLE - FIRM	VII B

SITE (CR)	HORIZON Pedogenic	HORIZON Geo. class	DEPTH (cm)	TEXTURE	COLOR	STRUCTURE grade size kind	CONSISTENCE	POROSITY RATING
D18 F	Ap1	A	0-18	C-SiC	10YR 5/2	wk-m f GR	FRIABLE	XI A
(2)	Ap2	AB	18-25	C-SiC	10YR 5/2	m m SAB - m f SAB	FIRM	XI B
	Bg	B	25-48	C	10YR 6/1 mat 7.5YR 5/8 mot	m f SAB	V. FIRM	X B
C	Ah	A	0-30	SiC	10YR 4/1	m-s m GR	FRIABLE	VII B
(1)	Bg	B	30-50	C	10YR 7/1 & 8/1 mat 7.5YR 4/8 mot	m f SAB	FIRM	VI A - VI B
D19 F	Ap1	A	0-20	C-SiC	10YR 3/2	m-s f SAB	FIRM	VI B
(5)	Ap2	AB	20-33	C-SiC	10YR 3/2	m m BL - wk f BL	V. FIRM	X B
	Bg	B	33-50	C-SiC	10YR 6/1 mat 7.5YR 5/8 mot	wk-m f SAB	FIRM	I A
C	Ah	A	0-27	SiC	10YR 3/2	m f GR	FRIABLE	VII B
(1)	Bg	B	27-50	C-SiC	10YR 6/1 mat 7.5YR 5/8 mot	f s SAB	FRIABLE - FIRM	VI B
D20 F	Ap	A	0-20	C-SiC	10YR 4/2	m m-f GR	FRIABLE	VII B
(1)	AB	A	20-30	C-SiC	10YR 4/2	m m SAB	FRIABLE - FIRM	VII B
	Bg	B	30-50	GRAVELLY SiC	10YR 4/2 mat 7.5YR 5/6 mot	m f SAB	FIRM	VII A - VI B
C	Ah	A	0-22	SiC	10YR 4/2	s c-f GR	FRIABLE	XII B
(1)	AB	A	22-40	SiC	10YR 4/2	m m SAB	FRIABLE	VII B
	Bg	B	40-60	SiC	10YR 5/2 mat 7.5YR 5/6 mot	s f SAB	FRIABLE - FIRM	VI B

APPENDIX 6

QUESTIONNAIRE

FARMER INTERVIEW

SOIL COMPACTION STUDY: FARMER INTERVIEWS

1. Landowner/Operator

Name: ____________________
Address: ____________________
Phone: ____________________
Location: ____________________
Date: ____________________

2. General Operation

Acres farmed: ____________________
Crops/acres: ____________________
Rotation: ____________________
Livestock: ____________________
Five year
History:
(Note changes) ____________________

Tractor(s)	2 or 4 w.h.	HP	Weight	Tire Sizes
______	______	______	______	______
______	______	______	______	______
______	______	______	______	______

3. Soil Compaction Assessment

No problem ________ Moderate problem ________
Serious problem ________ Unknown ________

4. Land Management Practices

____ Conventional ____________________
____ Conservation ____________________
____ Drainage ____________________
____ Liming ____________________

5. Concerns About Soil Quality

____ None ____________________
____ Erosion ____________________
____ Fertility ____________________
____ Other ____________________

FIELD SPECIFIC QUESTIONS

1. Cropping History:

Field 1

Crop Rotation: ______________________________
Years: 1987 ________; 1986 ________; 1984 ________;
1983 ________
Yields: 1987 ________; 1986 ________; 1984 ________;
1983 ________
Previous Cropping: ______________________________

Field 2

Crop Rotation: ______________________________
Years: 1987 ________; 1986 ________; 1984 ________;
1983 ________
Yields: 1987 ________; 1986 ________; 1984 ________;
1983 ________
Previous Cropping: ______________________________

Control

Type of Cover: ______________________________
Duration: ______________________________
Comments: ______________________________

2. Fertilizer Program

Field 1

Rates Applied: N ______ P ______ K ______ Other ______
Methods: ______________________________
Manure: (rate/date) ______________________________
Green manure: (crop/elimination) ______________________________

Field 2

Rates Applied: N ______ P ______ K ______ Other ______
Methods: ______________________________
Manure: (rate/date) ______________________________
Green manure: (crop/elimination) ______________________________

3.	Cultivation Practices	Size	Dates
Field 1			
"			
"			
Field 2			
"			
"			

4.	Fertilization	Size	Dates
Field 1			
"			
"			
Field 2			
"			
"			

	Seeding	Size	Dates
Field 1			
"			
"			
Field 2			
"			
"			

5.	Weed Control Methods	Size	Dates
Field 1			
"			
"			
Field 2			
"			
"			

6.	Harvesting Methods	Size	Axle Weight/Dates
Field 1			
"			
"			
Field 2			
"			
"			

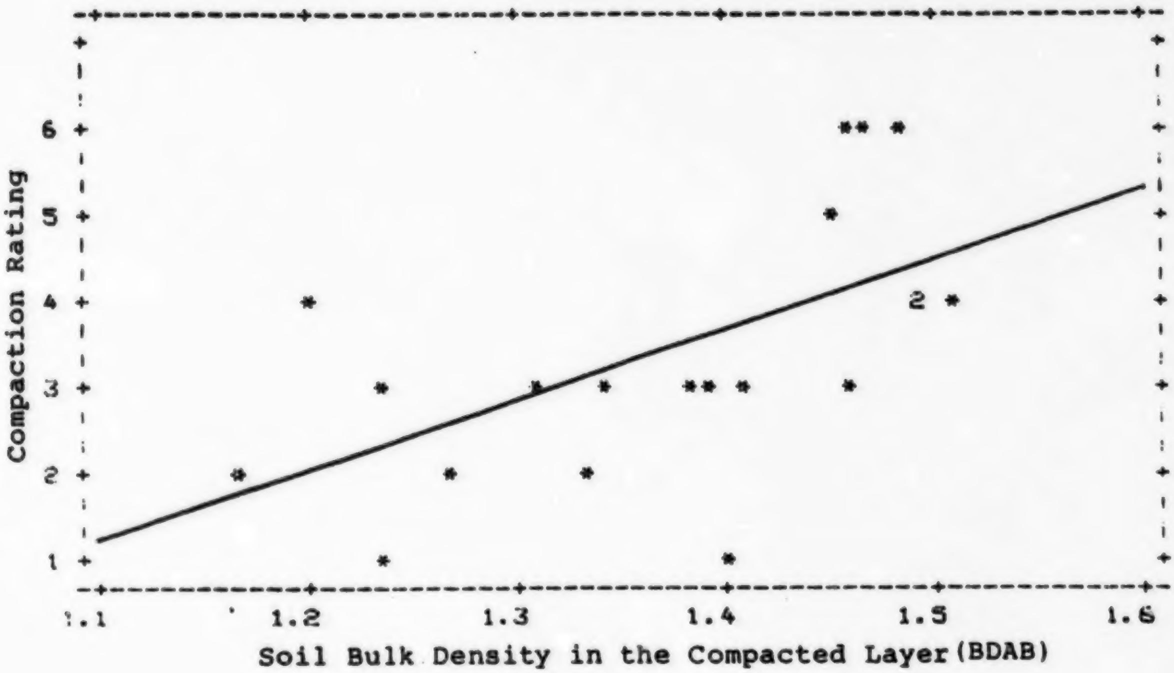
7.	Hauling Methods	Size	Axle Weight
Field 1			
"			
"			
Field 2			
"			

APPENDIX 7

REGRESSIONS OF

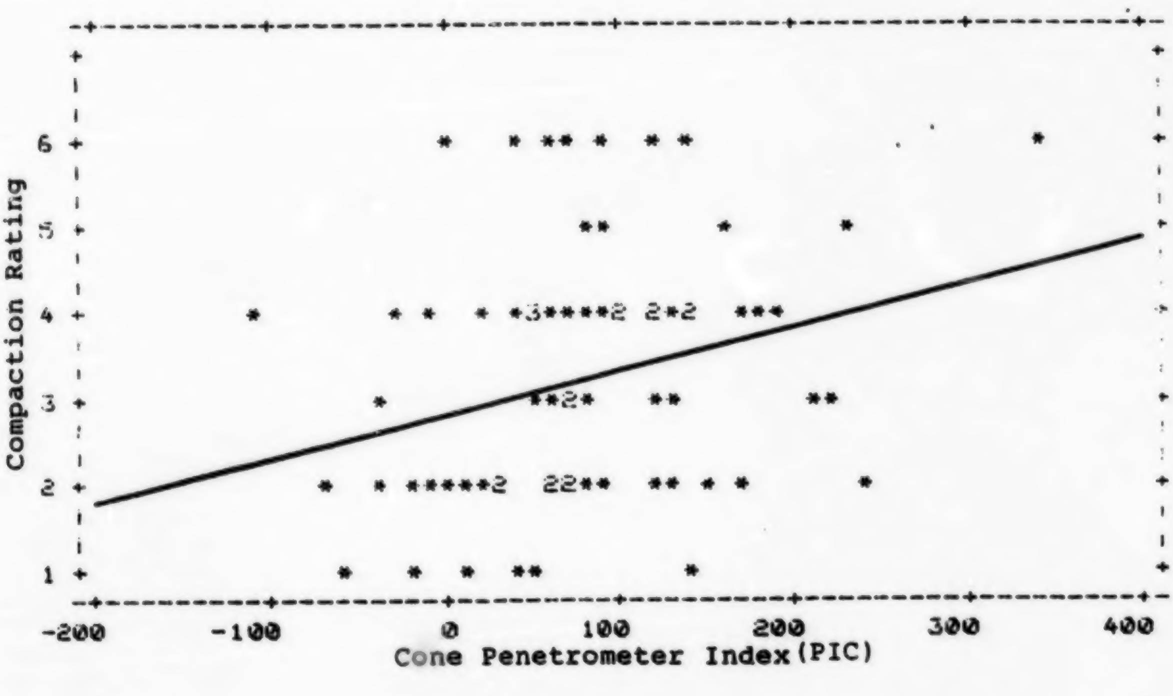
COMPACTION RATING VS BD,

PIC, PIH, and Pore AB



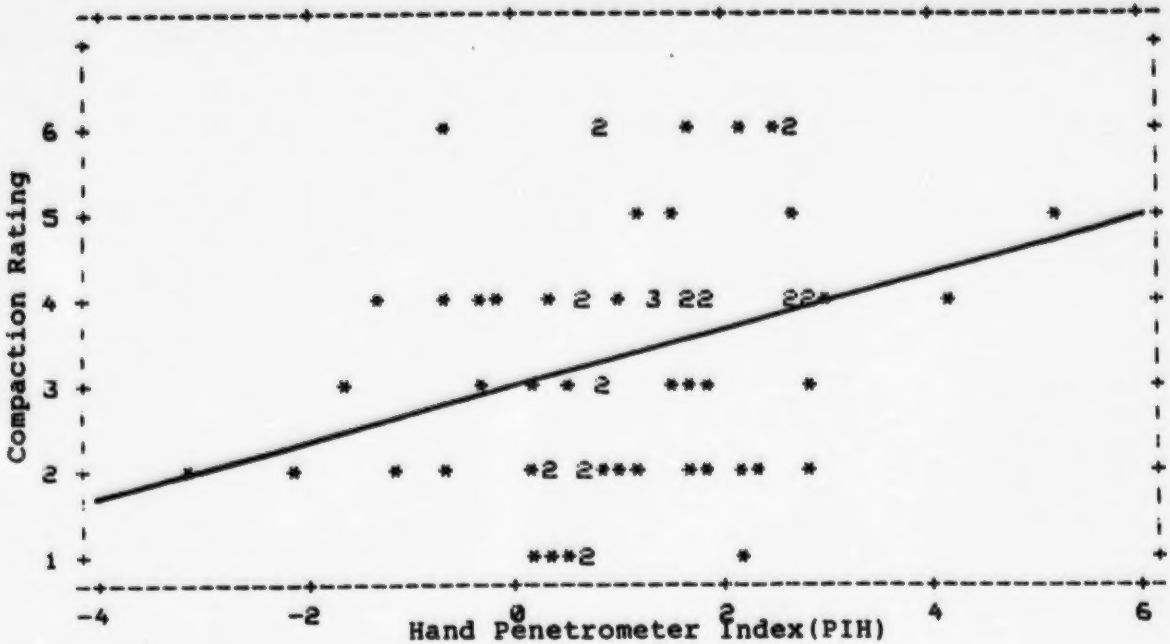
CR = 8.2(BD)-7.8 r^2 = 0.34

n = 20 P = 0.009



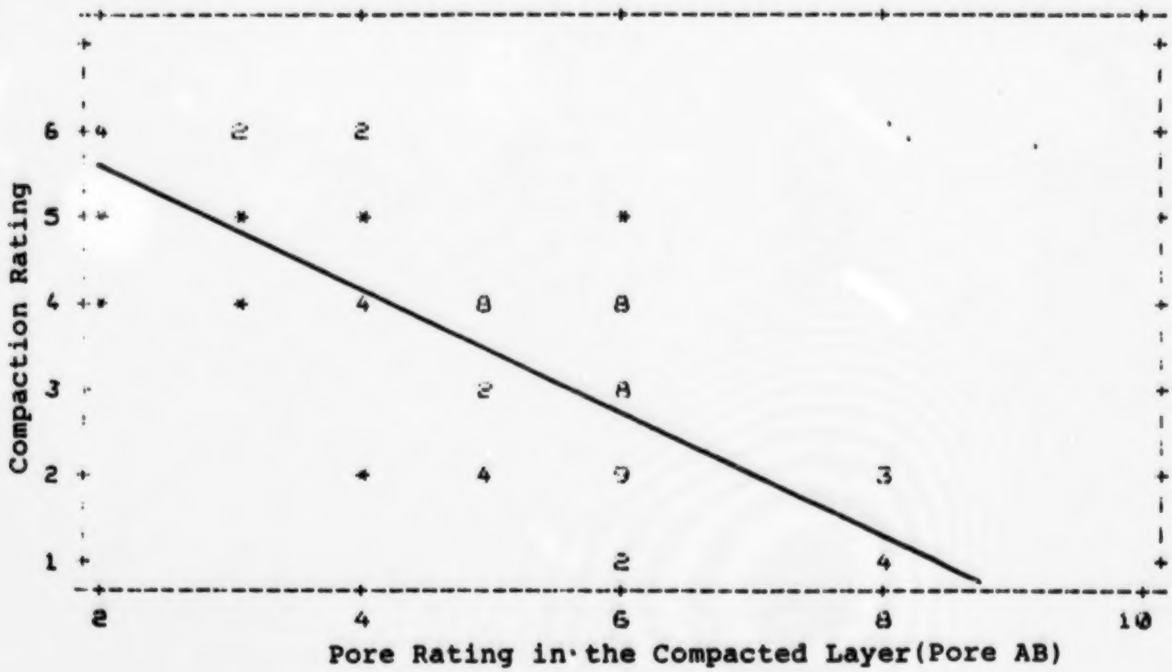
CR = 0.005(PIC) + 2.9 r^2 = 0.075

n = 70 P = 0.02



CR = 0.33(PIH) + 3 $\quad r^2$ = 0.1

n = 66 $\quad$ P = 0.009



CR = -0.71(Pore AB) + 7 $\quad r^2$ = 0.57

n = 70 $\quad$ P = 0.000